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# Journal
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W. F. G. Swann

**An Elementary Derivation of the Formula for the Windage Jump of a Spinning Shell**
James F. Heyda

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**Pioneer Biochemical Researches at the University of Pennsylvania**
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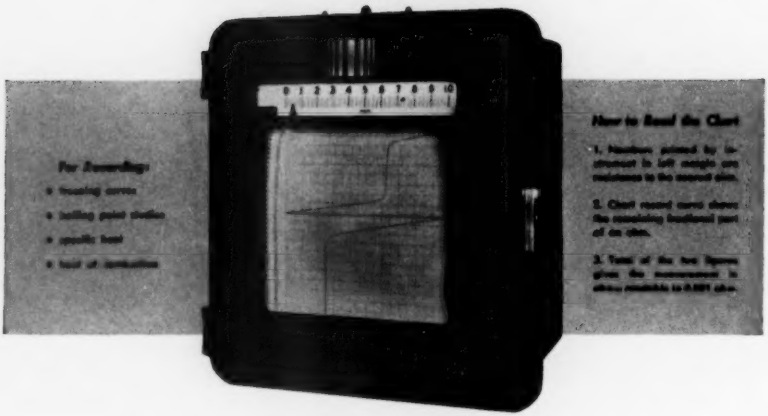
VOL. 261 NO. 6



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Entered as second-class matter March 14, 1928, at the post office at Lancaster, Pa., under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in paragraph (d-2), section 34.40, P. L. & R. of 1948, authorized on July 3, 1919.

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# RADIO'S ONE-WAY STREET

Dr. S. Weisbaum assembles an isolator which he developed for use in a new microwave system. Dr. Weisbaum is a Ph.D. in microwave spectroscopy from New York University. He is one of many young men at Bell Laboratories applying the insight of the physicist to develop new systems of communication.

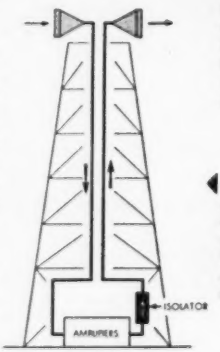
New radio relay systems for telephone and television now in the making will employ an ingenious device invented by Bell scientists. The device, known as an "isolator," senses which way microwaves are traveling through a waveguide, and stops those going the wrong way.

In the new systems a klystron wave generator sends signals through a waveguide to the antenna. The klystron must be shielded from waves reflected back along the waveguide by the antenna. The isolator stops reflections, yet allows the signals to go through clear and strong.

This isolator is a slab of ferrite which is mounted inside the waveguide, and is kept magnetized by a permanent magnet strapped to the outside. The magnetized ferrite pushes aside outgoing waves, while unwanted reflected waves are drawn into the ferrite and dissipated. This "field displacement" action results from the interplay between microwaves and a ferrite's spinning electrons.

This is another example of how Bell Telephone Laboratories research works to improve American telephony and telecommunications throughout the world.

The heart of the isolator is a ferrite slab. Geometric pattern is a carbon layer which dissipates reflected signals.




At a radio relay station an isolator assures one-way transmission from the output of the amplifier to the antenna.

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Published monthly by The Franklin Institute of the State of Pennsylvania, Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Pennsylvania. Printed by Lancaster Press, Inc., Prince and Lemon Sts., Lancaster, Pennsylvania.

Subscription rates: Domestic, $10.00 a year; Foreign, $11.00 a year. Single current issues, $1.00. Reprints, 50 cents per installment. All inquiries regarding subscriptions, change of address, sale of back issues and reprints, should be addressed to the Philadelphia office.

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**The Frank P. Brown Medal** (1938—Silver Medal).—This medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

**The Newcomen Medal** (1943—Gold Medal).—This medal is awarded, not oftener than once in three years, for achievement in the field of Steam.

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**The Boyden Premium** (1859).—This premium is awarded not oftener than once in five years to any resident of North America who has recently made a notable experimental determination of the speed, in free space, of radiation in any region of the entire spectrum.

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**The William M. Vermilye Medal** (1937—Bronze Medal).—This medal is awarded not oftener than biennially in recognition of outstanding contribution in the field of Industrial Management.

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**The Certificate of Merit** (1882).—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

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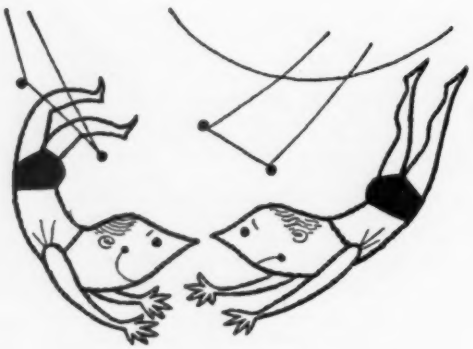

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Devoted to Science and the Mechanic Arts

Vol. 261 JUNE, 1956 No. 6

## A MESSAGE FROM THE RETIRING EDITOR

Twenty years ago, when I became Editor of the JOURNAL OF THE FRANKLIN INSTITUTE, the world of science was just beginning to realize the great practical potential of the earlier discoveries in radioactivity, quantum mechanics, relativity and atomic physics. The science of electronics was in its infancy, giant computers were still unknown, and the problem of unlocking the energy in the atom had not yet been solved.

It has been my privilege, as Editor of this JOURNAL devoted to all the physical sciences, to watch the rapid growth of a host of new developments in science and engineering. It is a source of real satisfaction to me to realize that this JOURNAL has, in no small measure, contributed to the furthering of basic scientific knowledge during the years of my tenure as Editor. It has been a prime publication outlet for the theoretical papers which preceded many of the present-day wonders of science—atomic energy, the electronic computing machines, servomechanisms, high frequency techniques, radar, guided missiles, automation, jet planes and many others.

In addition to the strictly scientific papers, it has been my pleasure to incorporate into the JOURNAL a little of the history of technology. Within these pages, during the last few years, are to be found the "technical autobiographies" of some of our present-day inventors, with the story of their problems and how they were solved.

Also, in the belief that specialists wish to avoid losing their sense of perspective, the JOURNAL has been publishing papers of general interest to scientists and laymen. In this way, the specialists can help to evaluate their own work against a broader background; and the educated layman can keep informed, in language he can understand, of the rapid pace of science.

It is with real regret that I write this message of farewell to the

JOURNAL. There is so much yet to be done in science that, like Franklin, I lament

> "The rapid Progress *true* Science now makes, occasions my regretting sometimes that I was born so soon."

The time has come, however, to close this particular chapter of JOURNAL history. I consider it a great honor to have had the privilege of serving as the ninth Editor of this old and distinguished publication. I wish particularly to give unlimited praise to our board of eminent Associate Editors, without whose untiring vigilance our high standards could not have been maintained. To each of them I extend my warmest personal thanks for their years of loyal service. To our Institute's Publications Committee, I add my real appreciation for their sympathetic council. And, last but not least, I give my sincere thanks to a hard working and most capable staff.

And now it affords me great pleasure to introduce the new Editor, Dr. John S. Burlew, Executive Vice President of The Franklin Institute. As a scientist, an author, an editor and an administrator, Dr. Burlew is well qualified to assume the leadership of the JOURNAL. Under his guidance, the JOURNAL will continue to serve, as it has for 130 years, the cosmopolitan needs of scientists, engineers and technologists in all fields of the physical sciences.

HENRY B. ALLEN
*Editor*

June 1, 1956

# NATURE AND THE MIND OF MAN *

BY

W. F. G. SWANN [1]

## INTRODUCTION

A crystal ball as a predictor of the future is a piece of equipment well known to the teller of fortunes, to the wizard who claims to see in the distorted forms which it presents to his vision the story of that which is to come. The crystal ball of the man of science is a structure with many facets and, by peering through these different facets in different ways, those who seek to learn of what is ahead see many different pictures which they embellish and interpret to their own satisfaction. Often do we find that the pictures formed by one individual in this way, the pictures by which, in imagination, he treads the path of the future, differ so greatly from those formed by another individual that the two find great difficulty in harmonizing their discussions. Those who, peering through their chosen facets, see pictures which have gained the greatest respect in predicting the future, naturally favor those pictures as fundamental. In due course, they are able to convert many of their fellows to the point of recognizing these forms of visualization of nature as reasonable ones, so that, as more and more converts to the philosophy become made, there becomes born to the mankind of that age a common sense, the common sense of the age.

## UNDERSTANDING

And so, the ideal of him who seeks to advance the frontier of knowledge has, in the past, been largely concerned with seeking at each stage the basis of what he calls an understanding of the phenomena around him. Much that is naive and dogmatic exists in this ambition for understanding. The pictures which an individual has accepted have been painted around the experiences of his generation. After he has lived with the pictures for some time they become very familiar to him and anything which happens according to their pattern is agreeable to him, so that he is apt to feel that he understands it. Often when we seek to trace this understanding to its origin, we find that it is based upon concepts of reality and upon convictions which, in the last analysis, call for as much understanding, in the sense in which the researcher seeks that goal, as do the things which constitute the elements of his immediate contemplation.

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* Lecture delivered at the Stated Meeting of The Franklin Institute, Wednesday, February 15, 1956.

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.

THE ROLE OF THEORIES

At any stage of this development mankind harmonizes that which is around him in terms of principles which he has come to accept. He forms, in fact, a theory. This theory has, in general, wider possibilities than the phenomena which have suggested it and, in tracing its ramifications, it is found to predict new things. These things are sought and frequently found. This is the constructive stage of the theory. It is the stage in which the theory says: "Try this, and ye shall find that." In this stage the theory performs a good service. After a time, most of the predictions of the theory have been exhausted and most of them have been experimentally tested and found true. That which remains seems to involve things which may probably be deemed to be covered somehow or other by the theory but in a form too complex for anyone to work out. Thus one has a kind of melancholy contentment in the fact that all that is worth doing has been done except things which would involve an enormous amount of labor in proportion to the return to be expected. The theory which in its youth was active in suggesting new things to do now adopts a negative attitude in asserting that "It is useless to try this and that because, if you do, you will not get any worthwhile results." "If you did," says the theory, "it would be contrary to my principles, which have become well established and which I have a right to hold to on account of my good deeds of the past." Then some young upstart does one of the absurd experiments and gets a result which is contrary to the theory. After a few lambastings by some of his more conservative colleagues, his experiments are confirmed by others and have to be accepted. Sometimes a slight modification of the theory will suffice to correlate the new phenomena. But sometimes, as indeed occurred during the transition about thirty years ago, the nature of the new phenomena is such as to strike at the very fundamentals of the old theory and call for a complete modification of viewpoint. Those who have grown old in the theory of the past will fail to understand the new concepts. They will say they have no meaning. Those who are born in these new concepts will say that they are the only things which have meaning and they will seek to represent the concepts of the old epoch as crude approximations to the philosophy of the new era. Once this new era has become established it takes over the duties of its predecessor. Again, it has a fruitful period in predicting new phenomena characteristic of its own realm, phenomena oft sought and found, and the prestige of the theory grows. As time progresses, one has to expect, however, an ageing of even the new theory and a repetition of that stalemate in which once more it seems that all worth doing has been done.

In the past, things developed comparatively slowly and the life of any particular form of philosophy might be measured in hundreds of

years. With the accelerated pace of modern times the replacement of the old by the new takes place more rapidly and there is sense to expecting a whole series of transitions in philosophy following in relatively rapid succession, each one giving hope of being the end point in the minds of its own devotees who have given it birth.

### COMMON SENSE

Each theory grows around itself an aura of common sense, the common sense of its epoch. This aura of common sense has a certain amount of elasticity within the domain of each successive theory, but experiences large jumps, calling for considerable mental adjustments in the transitions from one theory to another radically different from it. And so the center of gravity of common sense changes with the epoch, and the nonsense of the past becomes the common sense of the future.

Later, I shall speculate briefly as to the processes by which the brain operates in making its discoveries. For the moment, however, I should like to say a little concerned with the part played by that none-too-well defined concept called intuition.

### INTUITION

While intuition is born, for the most part, from experiences of the past, it makes its appearance in many different forms. In one form it represents the ability to surmize the truth of certain things without formal proof thereof, even to the extent of doubting the necessity of proof. Thus, a great many people would say that it is an obvious fact that the angles at the base of an isosceles triangle are equal. Yet we well know that the geometrical proof of this matter in the philosophy of Euclid's geometry is by no means easy. In fact, it constitutes Proposition 5 in the first of Euclid's books and became there known as the "asses' bridge" because many students of the subject were never able to pass beyond that bridge in their studies, or even to cross it. Here, prolonged experience of the truth of the statement usurps the discipline demanded by logic in the form of a rigid proof. When the laws of a subject are in a state in which they have not welded themselves into a prolonged experience, the mind is apt to be more cautious in making hazardous jumps to the formulation of conclusions. When the laws of the subject take the same general forms as those of some other domain with which we have lived for a long time, the jumps natural to the latter domain—jumps which are hazardous but no longer recognized as such—are apt to be transformed, and usually successfully, to the new domain. Here they provide short-cuts to conclusions and the mind, thus separating the wheat from the chaff, concentrates more intensely upon the vital elements of the domain to the exclusion of the more subsidiary elements.

INTUITION AND ANALOGY

It is a known fact that there is an exact mathematical analogy between the laws controlling the steady state flow of electric currents in conducting media and those controlling the relations between magnetic induction, magnetic field intensity, etc., in a problem having to do with magnetic materials. The analogy extends even to cases where Ohm's law is no longer assumed in the current problems and where $B$ is not proportional to $H$ in the magnetic problems. To every problem in one domain there corresponds an exactly equivalent problem in the other domain. However, it turns out that there is a wider range of experiences in the current domain than in the magnetic domain, so that all sorts of convenient developments have taken place in the former. There has arisen the concept of the resistance of a wire as a whole, as distinct from the specific resistance of its material, and with the birth of these subsidiary concepts have come all sorts of assumptions as to the truth of this and that. If we ever concerned ourselves with the question as to whether the current density was constant over the cross section of a cylindrical wire, we probably looked into the matter once and for all, and then forgot about it. If we were ever concerned about the meaningfulness of the resistance of a wire whose cross section varied from point to point, we probably satisfied ourselves with some kind of a proof and passed on. If we were ever concerned about the proper interpretation of resistances in series, or about what happens as the current flows from one cylindrical wire to another as regards the forms of the lines of flow near the places of junction, we drew rapidly upon our experience to satisfy ourselves that all was well. And so the theory of a Wheatstone's bridge, for example, presented itself as a matter of no great complexity. We even presented it to our high school classes, perhaps with no references to the troublesome details of which I have spoken. The conviction that all was well, a conviction founded upon our experience which controlled the factors which made all well, was so strong that we walked with security, and perhaps omitted to warn our pupils of the unseen hazards which they had taken in accompanying us on our journey.

If now we were presented with a corresponding problem in the magnetic domain, our conscience would not, in the initial instance, permit us to pass over some of these matters so lightly. However, in virtue of the exact mathematical analogy between the two domains, we can, with security, borrow the intuitions of one and extend them to the other. And so we build a device like a Wheatstone's bridge for a magnetic problem, with bars of magnetic material corresponding to the wires of the current problem, with a now well-defined magnetomotive force replacing the electromotive force, with what in terms of first principles would be a very mysterious quantity called reluctance replacing resistance, and with a device designed to determine when

there is zero magnetic flux through one of the bars replacing the galvanometer of the Wheatstone's bridge, and we leaven the abstract nature of our unfamiliar domain with the time-worn pictures of the domain which has lived with us.

When I was a young student, it was a customary procedure to make use of Maxwell's formulation of electromagnetic laws upon a dynamical basis to provide an intuitive understanding of electrical phenomena by an appeal to mechanical analogy. Thus, if we wanted to make somebody understand a circuit with self-induction, capacity and resistance, we would refer to a ball vibrating in a viscous fluid at the end of a spring. We would say: "Now the self-induction in this circuit is like that mass on the end of the spring. This capacity is like that spring. The electrical resistance of the wire is analogous to the viscous resistance of the liquid, and so forth." Today all of this appears to be changed. At an early age, before they learn anything about dynamics, youngsters start to play with radios and to acquire quite a little knowledge concerned with the essentials of their operation. And if the youngster wishes to understand the dynamical problem of how a ball bobs up and down on the end of a spring when immersed in oil, his teacher is apt to say: "Now this weight is just like that inductance in one of your radio circuits. The spring is like the capacity, the viscous resistance of the fluid is like the resistance of the wire. Now you know that the electrical circuit will oscillate; and in a similar kind of way, the ball and spring oscillate. You know that if the electrical circuit is stimulated by an external force of frequency equal to its own, it will resonate and build up a big amplitude; and for exactly similar reasons, the ball on the end of the spring builds up an amplitude when subjected to an external force which harmonizes with the system in frequency. Thus, since you understand all about the nature of the electrical oscillations of the circuit, you ought to be able to stimulate your brains to the point of understanding why and how a ball bobs up and down on the end of a spring in oil."

Another illustration of the way in which our intuitions can deceive us as to their fundamentality while nevertheless playing a useful role in our thoughts is represented by the following:

The science of electrostatics frequently starts with the concept of charges which produce an electric field composed of additive contributions from the individual charges, each charge producing, at a point $P$, a contribution to the field proportional to the strength of the charge and inversely proportional to the square of the distance from the charge. The concept of the field being represented as the derivative of a potential $V$ to which each charge pays a contribution inversely proportional to its distance from $P$ presents no serious difficulty. Here our intuitive concept is the charge, which we are prepared to endow with the characteristic of reality. As the subject advances, we become

introduced to Poisson's equation, or in a charge-free region, to Laplace's equation

$$\nabla^2 V = 0 \tag{1}$$

as the fundamental law governing matters, the actual solutions being controlled by the boundary conditions on $V$ or its normal derivatives. Here the naive mind is no longer as happy as it was at the beginning of the subject. Reality seems to have vanished. Even when the solution of the problem is attained, happiness is only restored when we have determined from it the distribution of the charges responsible for it. At this point our conviction of reality is reestablished. Suppose, however, that we are presented with a hydrodynamical problem in which an incompressible fluid, filling a container of, let us say, some irregular shape, moves about inside the container. Here, our intuitions seize upon the idea that the fluid must move in such a manner as—to put the matter in intuitive language—to avoid getting in its own way. To put the matter more exactly, we say that the fluid moves in such a manner as to satisfy the equation of continuity. No great obstacle to thought is presented by restricting ourselves to the case where the velocity of the fluid is derivable from a potential, and the equation governing this potential $\varphi$ is

$$\nabla^2 \varphi = 0 \tag{2}$$

which is of exactly the same form as (1), having the same possibilities as regards solutions. However, here the intuitions of the mind are content with (2), as representing the mutual pushing actions enabling the fluid to "keep out of its own way." If it now be asserted that $\varphi$ can be regarded as made up of a number of contributions originating on the boundary surface, the contributions coming from a distribution of fictitious doublets, whose individual positive and negative constituents each makes a contribution to $\varphi$ inversely proportional to its distance from the point $P$ where $\varphi$ is desired, if this be asserted, naive intuition will be offended. What reality is there in these doublets? is its demand. And so we see that in two problems which can be mathematically identical, intuition, like a chameleon, changes its aspect, depending upon what the mind chooses to regard as the realities of the problem in each case. The very concepts which it clings to as havens of reality in one problem offend it as inventions of the imagination in the solution of another problem governed by laws identical with that of the first problem.

So far, I have spoken of intuition in relation to different fields in which the laws are mathematically identical. When we are faced with a fundamental change in the forms of the laws, much that was formerly helpful in intuition born of analogy becomes of questionable value.

### THE CLAIMS OF CLASSICAL DYNAMICS

Even today, intuition strives to seek its basis in the classical theory of dynamics. To all who are more than sixty years of age, anything covered by this classical theory is regarded as satisfactory; it is understood. It is quite true that when Maxwell's electromagnetic theory made its appearance there was great turmoil in the brains of theoretical physicists to try and harmonize the structure with Newtonian theory. Maxwell went far to persuade his contemporaries that this could be done, and by striving hard for some five or six decades, physicists became more or less satisfied in the feeling that, to some extent, the ideal could be realized, but, having in their very search for this ideal, become broadened in concept and weakened in their devotion to pure Newtonian dynamics, were willing to say that, while the ideal had not been completely attained, the discrepancies did not matter anyhow. The mathematical physicist came to the point where he was willing to accept Maxwell's equations as a starting point with some contentment in the belief that Newtonian dynamics represented their mother even though there must remain some doubt as to who was their father.

Thus, by and large, even with the acceptance of electrodynamics, one had the feeling of comfort in anything which could be thought of according to Newtonian principles with such stretchings of those principles as were embodied in Maxwell's electrodynamics. In all of this period there was a hope that somehow or other in the luminescent aether, controlled according to the laws of Newton, one would find an ultimate explanation of everything. The firmness of this conviction was so great that, if explanations in this manner could be secured, the mind seemed to give a promise of demanding nothing further. The scheme of the Newtonian physics was the ultimate in satisfactoriness. As regards needs of explanation, its postulates represented that condition of nothingness which it seemed appropriate for man to take as his starting point for the elaboration of his thoughts. However, one has to realize that three hundred years ago, when Newtonian dynamics was born, there were quite different criteria for reasonableness and common sense than those which subsequently became born of that dynamics.

### INTUITION IN RELATION TO THE PAST AND THE PRESENT

And so, I try to picture the situation of one bred in these earlier thoughts who tries, in terms of them, to understand Newtonian astronomy as the philosopher of our age tries to understand the quantum theory in terms of that Newtonian dynamics. Our philosopher of three hundred years ago, in examining his bases of thought, realizes that the only way in which he can understand how a planet goes around the sun is to think of it as carried by an angel. It has to be an angel because an angel, being a supernatural body, invites no question as to

his powers of carrying on the duties assigned to him. In a sense, this ancient philosopher is more honest than we are. He does not seek to regard his postulates, his angels, as self-evident. He accepts them as things not understood and excuses himself from seeking an explanation of their origin and powers by asserting that his faith forbids him to inquire as to the origin of the power of the angels. He admits that they are his starting points, the place where his duties begin. And so, our ancient philosopher tries to understand why it is that the planet travels around the sun in an ellipse with the sun at one focus, approaching very near to the sun at perihelion and going very far from it, in an exaggerated case, at aphelion. He tries to understand this situation in terms of his criteria of common sense of the day. He does not have to seek very far for some comfort in the situation. It is very clear that, when the angel is near to the sun in perihelion he must be very uncomfortable on account of the intensity of heat radiation received, and this provides a very good reason for his moving very fast in order to get away from it. On the other hand, at aphelion he is a long way from the sun and he can afford to move more slowly. Doubtless, our philosopher, on the basis of this primary intuition, will try to carry matters further. It is obvious that the intensity of discomfort diminishes with increase of distance $r$ from the sun, so the philosopher defines a quantity $D$—discomfort—as

$$D = A/r,$$

where $A$ is a constant. This is about the simplest function of $r$ he can think of satisfying the criterion that it diminishes with increase of $r$. He now supposes that the angel, feeling the radiation coming to him in direct line from the sun, realizes that it will not avail him much to run away from the radiation by hastening along the direction of $r$ because the radiation will overtake him. He supposes the angel may conclude that he will get on better by moving "sideways" so as to dodge the radiation, and tries the assumption that the angel moves so that his velocity, resolved perpendicular to the radial direction, is proportional to the intensity of his discomfort. Thus, if $v_\theta$ is this velocity, he tries the assumption

$$v_\theta = aD = Aa/r$$

so that

$$rv_\theta = Aa = \text{const.} \tag{3}$$

But this is nothing more than the famous law of Kepler, which states that the planet moves in such a way as to map out equal areas in equal times, and is just the kind of law as is provided for by Newtonian Astronomy.

However, our philosopher, being also a mathematician, realizes that

(3) is not sufficient to determine the orbit of the angel, so he introduces another concept to supplement Discomfort—*viz.*, Joy. He assumes that the angel likes to move fast, and he tries how he may make use of a quantity $J$—measuring Joy—which he defines as

$$J = \alpha v^2,$$

where $v$ is the *resultant* velocity. And now our philosopher makes his second assumption to the effect that the angel moves in such a manner that the sum of his Joy and his Discomfort remains always the same, that is

$$\frac{d}{dt}(J + D) = 0$$

or

$$\frac{d}{dt}\left[\alpha(v_r^2 + v_\theta^2) + \frac{A}{r}\right] = 0. \tag{4}$$

Now it is easy to show from (4) and (3) that the angel moves in such a manner that[2]

$$2\alpha\ddot{r} - \frac{2\alpha v_\theta^2}{r} - \frac{A}{r^2} = 0. \tag{5}$$

Now (5) and (3) together are the Newtonian equations of motion of a particle of mass $m( = 2\alpha)$ moving under the inverse square law. And so we can see how our philosopher of old might have produced a kind of understanding of the Newtonian law in terms of his beliefs about angels.

Now I beg that you will not attribute to me personally any claims of reasonableness for the views of my ancient philosopher. I think I

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[2] Using coordinates $r$ and $\theta$, (4) becomes

$$\frac{d}{dt}\left(\alpha\dot{r}^2 + \alpha r^2\dot{\theta}^2 + \frac{A}{r}\right) = 0 \tag{6}$$

and (3) becomes

$$r^2\dot{\theta} = Aa. \tag{7}$$

(6) corresponds to the equation of conservation of energy which, of course, in conjunction with (7), determines the motion. However, to carry this matter through, we have, from (7)

$$\alpha r^2\dot{\theta}^2 = \frac{\alpha r^4\dot{\theta}^2}{r^2} = \frac{\alpha(Aa)^2}{r^2}$$

$$\frac{d}{dt}(\alpha r^2\dot{\theta}^2) = -\frac{2\alpha(Aa)^2\dot{r}}{r^3} = -\frac{2\alpha(Aa)^2}{r^4}r\dot{r} = -2\alpha r\dot{r}\dot{\theta}^2.$$

Thus (6) yields

$$\frac{d}{dt}(\alpha\dot{r}^2) - 2\alpha r\dot{r}\dot{\theta}^2 - \frac{A}{r^2}\dot{r} = 0,$$

that is,

$$2\alpha\ddot{r} - 2\alpha r\dot{\theta}^2 - \frac{A}{r^2} = 0$$

$$2\alpha\ddot{r} - \frac{2\alpha v_\theta^2}{r} - \frac{A}{r^2} = 0.$$

hear you proclaiming that in certain sections of the orbit the angel increases his discomfort by moving according to (3): and you will probably ask why Joy should be proportional to $v^2$ rather than to $v^4$. If you make these criticisms, I shall point out that I do not set up for my ancient philosopher criteria which he *ought* to have adopted according to your views of the fitness of things. I simply set up criteria which he might have adopted, and which, if he had adopted them, would have led to the Newtonian law and allowed him to make his arguments in terms of angels. I have no more respect for his *reasons* than you have, or than I would have for any reasons of a more modern vintage which were designed to "explain" the law of gravitation. If my ancient philosopher defines "Joy" as $\alpha v^2$, I am content to leave him in the happiness of his illusions if he thinks he knows why Joy should be proportional to $v^2$. Only if he presses his reasons upon me shall I have occasion to contend with him, just as I would contend with anyone who today tried to give me a reason as to why kinetic energy should be proportional to $v^2$ rather than $v^4$, other than the reason that the kind of kinetic energy which is proportional to $v^2$ turns out to have useful properties.

Now, having protected myself and my ancient philosopher from the consequences of his minor sins, I proceed to demolish him for what I deem his major sin. Suppose this philosopher had been quite successful in the matter of harmonizing gravitation with angels along such lines as I have indicated, I would assert that it still would have been a very bad thing for him to have done. It would have been a very bad thing for him to have sought comfort in this type of intuition, because I know that when he came on to more difficult problems, his intuitions would have caused him a great deal of trouble. I believe that it would have been very much better for him to have done what in actuality man subsequently did do, namely, to re-grow, even though slowly, a new type of intuition, founded not upon angels, but founded upon the Newtonian laws themselves. It is quite to be expected that the growth of this intuition might take a long time. In fact, it has taken many generations, but the end was finally secured in which contentment in conformity to Newtonian laws was regarded as a symbol of ultimate contentment.

And now, having fought for my ancient philosopher in the matter of his minor sins, and having executed him for his major sin, I must whisper that you and I are also guilty of this major sin, for in retaining intuition born even of the Newtonian theory to help us to understand something like the quantum theory, we are seeking in the wrong direction and committing again the major sin of my ancient philosopher. It should be our business, not to hang on to intuitions of the Newtonian era, but to remould intuitions on lines suggested by the quantum theory itself or by whatever other theory is to evolve. At first sight

such a suggestion is apt to be met with complete bewilderment as to the form which our intuition should take, but I believe that this is only a temporary barrier. It is probable that if, in order to correlate the principles of, let us say, the quantum theory, I have to take as my starting point certain postulates and ingrain them in my consciousness so firmly as intuition that they claim the right to suggest mathematical structure, and even, following the patterns of old intuitions, to suggest such structure outside of the realms in which the intuitions were formed; if I do this, I shall experience a certain amount of guilt and unsatisfactoriness of procedure, but I think that if I go far enough in a search for the origin of this guilt, I shall find that it is merely the grumbling of the discarded Newtonian theory emanating from the dungeons to which he has been relegated. We have some examples of situations in which the kind of thing which I am speaking of has been carried out more or less unconsciously. A particular case is represented by the restricted theory of relativity.

The restricted theory of relativity, of course, had its beginnings in electrodynamics and in particular in the behavior of the Maxwell-Lorentz equations under what is generally called the Lorentzian transformation. In this epoch, the general intuitive basis of thinking was to the effect that there was meaning to an absolute measurement of space and time, but that if a body was in motion, then, on account of mysterious forces concerned with the structure of matter, everything about the matter was altered. As regards time, all the clocks went at different rates from what they went at before, and clocks which went simultaneously before, no longer went simultaneously. Moreover, lengths were altered, and intuition perpetuated the spectacle to the extent of saying that the reason we do not observe all of this is that all things alter in the same way and therefore we are totally incognizant of anything having happened. In other words, there was a faith in a kind of basic meaning to absolute space and time, and superposed upon this there was a mysterious kind of compensation resulting from the effects of motion in which everything was really extremely complicated in the fundamental sense, but the complication was concealed on account of the way in which the measures were altered in the same manner as were the things which were being measured. It wasn't very long before this whole view became discarded, at least in the minds of those who had most to deal with the theory of relativity. It became quite belligerently asserted by such people that it was wrong to think in this way, that there were no absolute measures of space and time, and that the measures of the so-called moving observer were just as absolute as were the measures of the fixed observer. And so one demoted the fundamentality of absolute space and time from the position which it formerly occupied and became content to speak in terms of an infinite number of possibilities

of attaching numbers, $x$, $y$, $z$, and $t$, to the so-called events of nature, placing all of these measures more or less upon an equal plane.

### THE EVOLUTION, ENRICHMENT AND MODIFICATION OF OUR BASIC CONCEPTS WITH GROWTH OF OUR EXPERIENCE

In the past it has been a matter of wide acceptance in science that there are certain things, so-called material bodies, which are responsible for the happenings in the universe, in the same sort of way as that in which human beings are regarded as responsible for much of what goes on in the world around them. Passing over that period of history in which the heavenly bodies were "gods" with all the anciently believed characteristics of such deities, I suppose that in the modern, or semi-modern periods, things may be said to have started when people sought to understand the Newtonian Theory of Gravitation. Many have sought contentment in the thought that the sun stretched out some kind of tentacles which held the earth in its place. If some philosopher had questioned whether the sun did anything at all and argued that we should think rather of the space around our planet as being in a curious condition which provides for the apparent pull exerted upon it and that the sun is merely the symbol of that condition, the practical man could have argued, with reasonably good philosophy, that if the sun were not there, there would be no pull at all and that this is all that he means when he says the sun is responsible for the pull. And so the phenomenon of the active entity $A$, the sun, pulling another entity, $B$, came to mean simply that the pull on $B$ could be described in terms of $A$, that is, in terms of its position in relation to $B$, and possibly its velocity, acceleration, or what not.

When the electron came along, it was introduced as a child born in the domain of the Maxwell-Lorentz theory, and like a prince born to the purple, its activities were prescribed for it by the laws of the land which gave it birth. What came to be called an electric field was, by those very laws, calculable in terms of the doings, the wiggles, if you like, of the charges, the electrons, etc. And what can be called the force produced by the field on any one charge is described in terms of the doings (occupation of known positions, possession of certain velocities, etc.) of the other charges which, without conflict with logic, could therefore be asserted as being *responsible* for these forces. And so, there arose the earlier attempts at atomic theory, in which it was reasonably clear as to how the electrons, etc., performed their functions in the theory, but, alas, the predictions of the theory did not fit the facts! And so, there arose the Bohr Theory in which the electrons were retained in the picture, but were relieved of the responsibility of doing anything. The electrons were allowed a certain place of conspicuousness in the picture in that they were permitted to travel in planetary orbits around a central region, the nucleus of the atom, but

they were denied the responsibility of emitting light radiation, which formerly had been their true job, because what appeared to be their natural way of emitting this radiation did not agree with the facts. They were, nevertheless, given the credit of emitting the radiation, but in a way about which nothing was said. At this stage, the electron was like the former head of an organization who, in his day, had controlled everything, but who, as the necessities of development demanded a change in the organization, had relinquished his former duties to others. However, the old gentleman was given a place of honor and was allowed to perpetuate some of the rituals, the planetary orbits, of his former leadership. His picture hung upon the wall, and whenever the organization did anything, those concerned bowed to the picture and proclaimed that what had been done was done in his name. In the ritual of the Bohr theory, when the electron jumped from one orbit to another, radiation was said to be emitted and the electron got the credit, although nothing was said or known about the way in which he was supposed to have produced the radiation. And then there came the modern quantum theory, in which the electron's rituals became rather a nuisance and got in the way of the new activities, so the old gentleman was kicked out in actuality, but, nevertheless, with some dignity. Moreover, he attended the first meeting of the committee which was to decide upon the new course of action to be taken in relation to atomic affairs, and he attended clad in his ancient distinguished robes of the order "Hamiltonian." In this form, he appeared ready to dictate the course of action again, but before he got going, he was ushered out of the building and things were carried on in the spirit of the new regime. However, a few ornaments were culled from his robes, and a few of his phrases were retained with modified meanings. Finally, however, and in honor of his memory, when any ultimate act was consummated, even in this new regime, the act was performed in the name of the old gentleman whose picture still hung upon the wall. In other words, the electron was said to have made a transition from one state to another and to have radiated energy in the process, or to have tunneled through a potential barrier, or to have done any one of the dozen other marvelous things, concerning which it was the height of atomic impropriety to inquire how he did them or even to ask for a photograph of him while he did them!

Of the many so-called atomic particles now playing a role in atomic theory, the electron was merely the first. It was soon followed by the proton, which carries a positive charge, and, for a time, in the pre-quantum theory era, the Club of Atomic Particles was closed. Nature, at that time, seemed to have confessed to a structure of matter which was purely electrical, and nothing which could not be fashioned out of electricity made sense. Then came the neutron—the neutral particle—truly a monstrosity in an age when the Maxwell-Lorentz theory seemed

to have established a valid claim to govern the universe. Following the neutron, there came, with increasing frequency of revelation, more and more particles, the neutrino, the mesotron of cosmic rays, and then a host of relatives in the form of all sorts of different mesotrons, so that mankind lost the sensitivity to be shocked at the appearance of any new entity in the atomic realm. He even became careless in inquiring as to the credentials of these entities, and as to whether the habits which they were supposed to possess in order to perform the functions which they were supposed to perform would guarantee for them positions as worthy members of the society which they had joined.

As in the case of the electron, each of these particles seems to claim a potentiality of *doing* things, although when we come to examine things closely enough, the story of the actual doing is never written. The most that can be said about them in this matter is that when certain things happen they are regarded as being on hand. In a sense, and in relation to the actual happenings in atomic physics, these particles are to be likened to the flags of nations. If, in the desert, I come upon a flag of some country, I know the kind of situation which I may expect to find as I travel to the place where I see the flag. The flag, itself, does not create the situation, but its presence is something which guarantees the existence of the solution.

Even in this limited role of adorning the scenery in such fashion as to announce what is going on, the quantum theory seeks to demand for these particles activities calculated to shock severely the materialistic mind. However, the quantum theory is a domain so difficult of comprehension by the ordinary layman that the unconventional behaviors which it demands in the particles have escaped the attention of most people, and with attention dormant, alarm is not called for. Those who work in the domain of the quantum theory are so concerned with its mathematical manipulations that they have no time nor inclination to voice aloud its philosophic implications. Yet these implications, if so voiced, would stagger the beliefs of most individuals by revealing to them the fact that these men of science, so materialistic in the layman's appraisal of them, are occupied with thoughts which, if interpreted in ordinary language, would destroy every vestige of the layman's materialistic foundations and clash with the intuition of such horse-sense as he thought he had by inviting him to leave that kind of sense strictly to horses and the like.

Man is indeed a curious animal who in his religious faiths professes beliefs in certain things which would jar his naive philosophy beyond measure if he dared to allow himself to meditate upon these things as real circumstances to be thought of as operative outside of the abstract realm which he reserves for his religious devotions.

Let us compare some of the ideas which are probably the stock-in-trade of most laymen with ideas which every atomic physicist accepts,

at least when acting in his professional capacity as a scientist. Let us imagine a conversation between a conventional layman and an atomic physicist who has ceased to be frightened by his own ideas when extended beyond the realm of his professional activities.

"Mr. Layman," says Mr. Atomic Physicist, "do you believe in anything outside of the realm of your daily activities?"

"Oh yes," says Mr. Layman, "I believe in a hereafter, I believe in the principles of the Christian religion, and, naturally, I believe in a Universal Deity."

Says Mr. Atomic Physicist, "Do you believe that beings other than mortals exist, and do you believe in them as firmly as you think you believe in the existence of that table which I believe I see before me?"

"Well," says Mr. Layman, "I do not know that I can answer that very strongly in the affirmative. It is doubtful, indeed, whether we should inquire too much about these matters. We must have faith and believe that what has been handed down to us by posterity is something which has its effect upon our lives, gives us comfort and, to a great extent, guides our actions. Naturally, we must expect that beings other than mortals have characteristics and powers different from ours."

"Mr. Layman," says Mr. Physicist, "do you think it would be consistent with the fundamentals of common sense to believe that such a being could disappear from one place and appear, practically instantaneously, at another without passing through the space between?"

"Oh," replies Mr. Layman, "I do not think it is right to introduce such bizarre ideas as that. It is much better for us to admit that we do not understand what is happening and agree not to be too specific in introducing such nonsensical illustrations as you have voiced."

"But," says Mr. Physicist, "why do you say that this idea is nonsensical?"

"Well," says Mr. Layman, "such an idea is contrary to everything that I regard as real, and I regard discarnate human beings as real. It would make nonsense to me to have any such thoughts as you cite."

"And now," says Mr. Physicist, "I wonder whether you know that if I, in my professional capacity, should think of an electron as being at one place and then being at another place as a result of having passed through the space between, I should be dubbed as a propagator of nonsense by my colleagues. They would regard my remarks as nonsensical, as nonsensical as you have regarded the thought of anything disappearing in one place and appearing in another without going through the space between. My colleagues would tell me that in our philosophy there is no meaning to the passage of the electron from one place to another. Things do not move, they simply disappear and reappear.

"But, Mr. Layman, let me ask you another question. Suppose

you should see a man and a woman engaged in conversation and suppose that, in the middle of the conversation, they both disappeared, with no evidence of anything being left, except that occasionally at some distant place, and at a time following very closely upon that of the disappearance, two new beings were suddenly born out of nothing—one male and one female. What do you think of that thought, Mr. Layman?"

"I think," says Mr. Layman, "that such a thought is completely fantastic."

"But," says Mr. Physicist, "this is exactly what we believe to happen when a negatively charged and positively charged electron meet and join in what we may call 'atomic conversation.' As a matter of fact, our theories introduce a new actor in this realm—one whom I suppose you may call a 'ghost'—we call him a photon. He does not have material existence in the sense in which you as a layman would probably regard such existence—he is much more like what you would regard as a ghost than anything else. To the quantum theorist he possesses the power to absorb the essentials—souls or what not—of the evaporated particles which have disappeared and materialize them again into positive and negative electrons in another place."

Now I know that my colleagues among the physicists will argue that these peculiar happenings which I have referred to in relation to the quantum theory, happenings in which something disappears in one place and appears in another without going through the space between, are phenomena concerned with the small-grained structure of matter, and even the quantum theorist will tell you that when you take averages, matter as a whole behaves as the layman thinks it behaves. However, I suspect that our normal antagonism to belief in the occurrence of things correspondingly remarkable in the large scale affairs of men is not founded so much upon our relegation of such phenomena to the realm of atomic physics as upon the fundamental abhorrence of the idea that anything can happen in so bizarre a fashion. We fail to hang the atomic physicist, not because we believe that things can be all right in his realm and nonsensical in the realm which we picture as that of our lives, but because we do not know enough about what the atomic physicist is doing to be sure that we can really understand what he is talking about. Where ignorance is bliss, 'tis folly to be wise. And so we live in contentment in this ignorance, happy in the belief that it cannot in any way disturb us.

### LAWS AS CONSTRUCTS OF THE MIND OF MAN

And now, having, as it were, dematerialized most of the things which, in the primitive picture, masquerade as the realities of nature, it is meet to inquire how far these things are creations of the mind of man, as the flags of countries and the symbols of mankind are things of such creation.

I recall a remark by the late Sir Arthur Eddington who, at the time, was discussing the problem of the number of electrons in the universe and gave reasons for believing it to be $1.57\cdots \times 10^{79}$—that is, $1.57\cdots$ multiplied by one, with 79 zeros after it. Eddington remarked that one might naturally raise the question as to whether it would have been possible for the Creator to have put just one more electron in the universe than the number here represented, and if not, why not. Eddington went on to say that the answer to this question was to be met by asserting that the question was not one which should have been asked. The question which *should* have been asked concerns why the mind of man has been so constituted as to analyze the universe into a structure composing exactly this number of electrons.

Now such a statement was not, of course, very intuitively obvious in its meaning, at least to what we may call the laboratory man. However, I will take an example of it which may perhaps be more familiar to the physicist, and which nevertheless illustrates the same thing. And so I consider a box containing nothing in the form of matter and which therefore has presumably electromagnetic radiation—heat radiation—in it. Following the normal procedure, I analyze this radiation into its various wavelengths, its frequencies of vibration, and I find that the number of frequencies between any two assigned frequencies, let us say, the number between 10,000 and 11,000 vibrations per second, is a perfectly definite number depending upon the size of the box and upon the fact that I have made what is called a Fourier analysis. Now standing beside me I suppose that there is an ultra-materialistic individual who speaks of photons and says that he believes that, in the last analysis, a photon is really a nice round ball and each one of these frequencies corresponds to a definite photon. And so, having performed my analysis, this horse-sense physicist says to me: "All those frequencies which you calculated are really round balls and they are photons." I say: "But are they all present?" He says: "No, they are not all present necessarily at any one time, but the only ones which are present are in the category which you counted. There are no photons in there which are associated with the frequencies other than those which you have counted." But I become a little worried about this. I take a box twice the size of the original box and I perform my analysis again and I say to my materialistic friend: "I find that there are twice the number of frequencies between 10,000 and 11,000 than I found before." He says: "Of course, any fool would know that. You double the size of the box, and you double the number of photons." However I say: "Yes, my friend, but it is not quite as simple as that because these additional photons are not merely copies of the old photons. They have come into existence, not by duplication, but by interpolation. In other words, my analysis is more fine-grained than it was before and there are many photons in my

double-sized box which have frequencies not to be found in the photons in the old box. And moreover," I will say to him, "it occurs to me that if, instead of taking a box just twice the size, I had taken a box which was nearly twice the size, so that there was an incommensurable ratio between the volumes of the boxes, then no one of the photons which I produced in the double-sized box would be found in the original box." And I go on still further and say "You know, I realize that this doesn't depend upon the fact of my having a box at all. I can simply *think* about these boxes, and *you* must change the material nature of your round-ball photons to match the caprices of my thoughts."

Now I hasten to remark that, in a philosophy in which one comes to recognize expression of the laws of nature as constructs of the mind of man, we must not suppose that the constructs have been made independently of nature. The task of observation remains as firmly a product of nature as in the crudest mechanical picture. It is only the super-scaffolding which has been erected by man to harmonize these facts that can claim to be a pure child of the mind. However, in this child there arise new elements which play such a vital role in the structure that they may well claim prestige among those entities which the physicist in the past has called real things. In this matter, one has to confront himself with two possibilities. He may suppose that there are some *real* real things like electrons, which are of nature herself, and that some of the constructs, such as photons, have a less dignified claim to reality in that they are nothing more than constructs of the mind. On the other hand, he may maintain, in a manner very nearly approached by the remark of Eddington to which I have referred, that all those things which we call real in the ordinary sense of the word are constructs of the mind of man and only our sense impressions remain; for, in the last analysis, everything that man does in science is based upon a utilization, harmonization, and extension of his sense impressions. On this view, the constructs which have posed with such confidence as the realities of nature are merely concepts invented by the brain of man to coordinate his sense impressions. Truly, constructs of man's invention are extremely useful, as the schemes for cataloguing books in a library are useful; but the schemes of cataloguing are not themselves the books of the library themselves. If you still crave reality in this view of things, I fear I can give you little comfort. I can only soliloquize in words I have used before to warn you of the illusions which your search invites.

"Ah, Reality, that will-o'-the-wisp of philosophy. You may think you have it in your hand but to find that you have but the shadow of something else. You will pursue that something else; you will clutch it, and again it will feel real until you find that your consciousness of its touch is no more than the tingle of your own blood as your hands clasp upon it. Reality is the most alluring of all courtesans, for she

appears to each man in the light in which he would have her; but she is no rock on which to anchor your soul, for her substance is of the stuff of shadows; she has no existence outside your own dreams and is oft no more than the reflection of your own thoughts shining upon the face of nature."

It may be well argued that if man relegates to himself the task of inventing laws of nature for the purpose of ultimately correlating his sense impressions, there is no guarantee that he may not be able to do this in more ways than one. This is indeed true, there is in fact good reason to believe that he may be able to do it in an infinite number of ways. What then is his goal in this matter? It is reasonable to say that his goal is to correlate the phenomena with which he is already acquainted in the simplest way consistent with a proper regard for fruitfulness. And what do we mean by fruitfulness? We can but mean that the framework which man invents to correlate what he already knows is fruitful if, in its structure, it suggests other things which he might seek for and which, if he find them, can be correlated into his whole scheme of material knowledge—or, if you like, his whole scheme of sense impressions.

### INTUITION IN THE ABSTRACT DOMAIN

And what is the role of intuition in this task in which science is concerned with merely constructing a framework to embody his experiences? In the first place, there comes ingenuity, the ingenuity of utilizing the tools which one has, tools mainly of a mathematical kind, for the purpose of the correlation desired. The evidence of the exercise of this ingenuity is to be found in the whole history of the growth of science. It consists in large part in observing the peculiarities of what nature reveals to us, of inventing constructs useful for the harmonization of these peculiarities, and finding the tricks of scaffold building, of mathematical correlations, which are well designed to mimic what we observe in the picture which nature has presented to us. And when this is done, we usually find that, as the scenery of our studies changes by the opening of new horizons of knowledge, the ultimate mathematical properties which are effective are used again, but with different so-called physical meanings attached. And so we find the properties of Fourier series, and of normal functions in general, continuing to play their role in the new era as in the old. These properties mirror such facts as are represented by selection rules in spectroscopy. Product terms in Lagrangian functions or their descendants continue to provide the means by which interaction between different systems are represented: and there are many other illustrations.

And so these old warriors, which are ultimately the properties of analytic functions of our science of mathematics stand immorally ready to serve any new master in whose service they may be invoked.

In the change from one master to another, the heraldic uniform is redesigned, but when the sword is drawn ultimately for action, it is the same old sword which does the trick. In an era in which the "models" of bygone days have evaporated, the mathematical physicist does well to concentrate his ingenuity upon the mathematical formalism itself, and exercise a new kind of intuition, an intuition which extrapolates the potentialities of mathematical form in a manner analogous to that in which, in former days, he extrapolated the old pictures of mechanistic activity.

### HARMONIZATION OF DIFFERENT FIELDS OF KNOWLEDGE

Often we become concerned with the apparent failure of different branches of knowledge to harmonize. Physics stands in one corner, biology in another, aesthetics in another, and the language of one is confusing to the other.

If, to take an illustration, we should imagine the complete story of the universe governed by mathematical differential equations of some kind, there would be many different solutions of the equations. The solutions would have characteristics very different from one another, in spite of the harmonization through the differential equations which represent the parentage of all. One of these solutions might represent the phenomena we usually deal with in physics. Another might concern biology, aesthetics, or even theological matters, and the bridge of understanding would arise from the existence of the fundamental differential equations. However, in practice, we have encountered these several domains independently, and in any one limited domain it has been possible to construct a scheme of correlation more suitable for that domain than the scheme which might be imagined to have been precipitated from the general theory covering all domains. Even in the limited domain of physics, it is more convenient, for example, to mark off a sub-domain—geometrical optics—as of use for the construction of spectacles, than to evolve such appliances from the more general quantum theory of light.

Now in the construction of laws of limited generality for the separate domains of knowledge, we have, as it were, destroyed the bridges which connected the different domains. Moreover, each domain has grown its own language and its own intuitions, its own pictures, which are simpler for the necessities of the limited domain than they would have been had they been charged with the responsibility of recognizing *all* domains in their ramifications. Thus, while the general theory embracing all domains permits a smooth passage from one to another, the specialized pictures and intuitions of the several domains will not extrapolate from one to the other, and if accepted in too fundamental a light, they may stand with each one of them decrying as nonsense the precepts of all others.

THE ROLE OF THE BRAIN OF MAN

It may sometimes be maintained that if a theory, a new theory, for example, is expressed in correct language and is logically unassailable, it should be capable of being understood by a reasonably good man of science. I think there is much to say against this view. There are, in fact, three things in a theory in its relation to an individual. There is nature, there is the mathematical structure itself, and there is the brain of the individual who wishes to comprehend it. It is first necessary that there shall be a proper one to one correspondence between the phenomena of nature and the predictions of the theory. And then, I think we must maintain that it is further necessary that there shall be a one to one correspondence between both of these domains and something in the brain of the individual himself.

In these days we hear very provocative suggestions concerning similarities between computing machines and the human brain. By its power to make rapid calculations of the various chances presented in a game, it is possible to devise a machine which can play a game of chess, and indeed win the game against a human being in an appreciable number of cases. It may be argued, however, that such a machine can never make a discovery, it can never produce more than the consequences of what is put into it. That is, of course, true, but its truth includes wide ramifications. If, through couplings to its surroundings by various devices, it is made sensitive to those devices, it can grow in its operations the characteristics of experiences which play so great a part in the activities of man. So far there is a close parallel between the machine and the human brain, except that, as I am informed, while the machines can arrive at their conclusions enormously more rapidly than can man, their memory capacity and all that goes with it, is, in the case of the biggest machines, only the equivalent of that of an earth worm.

One of the characteristics of inventiveness in theoretical physics is the apparent power to strike ahead of past experience, anticipate and find new things not yet in the category of the things of experience. I have already spoken of such a power as an attribute of a theory. A theory designed to correlate the known facts will, in itself, contain consequences outside of the realm of those facts. Indeed, there may be several theories covering the same known facts but having widely different predictions outside of the realm of the known facts. The good theory is one whose predictions of this kind correspond to the facts of future experimental discoveries. And so, in line with what I have already suggested, we may think of the brain as developing first a structure with a one to one correspondence with the facts. However, we may envisage this structure as having, like a theory of the phenomenon, a much wider range of potentialities than the facts themselves, so that new candidates for facts are suggested, as indeed they would be

by the corresponding theory. So far the brain and the theory play parallel roles, or, if you will, have parallel designs. But there is something more to be said. Just as there may exist abstract theories for which no brain pattern has developed except in the minds of their initiators, so there may grow in the mind of man a brain pattern covering nature as known in the past with an extension of the pattern into the future, without anyone having set up the mathematical theory which corresponds to that brain pattern. Indeed, it is conceivable that the brain, in response to the promptings of the facts of nature, may in all, or in most, cases grow its own brain structure to correspond to, and possibly extend, the known facts before developing the other partner which becomes printed in the book—the mathematical theory. It is possible that the brain structure may develop first in a kind of embryonic stage, subsequently seeking formalization in some disciplined and manipulatable form which it finally formulates in a theory, and that the theory and the brain structure develop from here on in the particular pattern of that theory. Indeed, it may be that the physiological development of the brain pattern constitutes a more powerful means of setting up a one to one correspondence with nature than is possible in terms of mathematics, or at any rate within the bounds in which man today can handle mathematics. Thus, for example, the brain pattern might involve what, in mathematical representation, would be all sorts of complications such as are met with in non-linear differential equations. While the brain pattern would hold in its design a means of tracing these things to their consequences, the mathematician of today, even though he could present some of the fundamentals in mathematical form, would not have the power to follow them to their conclusions. To take a very crude analogy, suppose the brain contemplates a complicated dynamical problem where it could never solve the mathematical equations concerned, and suppose that it grows an electrical structure of the kind known to the engineer as an electrical analogue. Then this analogue can function to the final solutions of all problems without the burden of formulating mathematical solutions as intermediaries.

It may be of interest to ask in what form a brain which had developed, in its own right, a one to one correspondence with nature as the result of profound meditation, not necessarily along the lines of mathematics, how such a brain would develop the further consequences of its own achievements. How, in fact, would it extrapolate the pattern which it had already developed into further domains in the hope of enriching its present correspondence with the known to a future correspondence with the unknown? It would seem that such a brain would operate on the basis of what we may call pure intuition. To put the matter very crudely, the design of such a brain would be such as to produce, in its owner, conviction as to the truth of such and

such a phenomenon, and perhaps one not as yet discovered. Here, in all verity, we would have the culmination of intuition and the dream of the genius would be realized. Thoughts simply come to him and they come with the certificates of truth. If the brain is asked the reasons for its assertions, it can only reply: "I need no reasons, I *know*." Perhaps herein lies the formalization of "Faith" in theology. However, even if this rather fantastic situation should prevail, we must not expect that the intuition of the being concerned would always fit with nature; for just as a good mathematical theory covering present day facts and having a good change of predicting new facts may, nevertheless, fail in its predictions when it wanders too far from the realm of past experience, so a brain which has grown a design to correlate the present may, with some confidence, extend the predictions of that design into realms not too far removed from those concerned with the present but may, as it wanders from such realms, make predictions which do not harmonize with nature. As new facts developed, it would be necessary for such a brain to reform its pattern so that at each stage of its development it became chiselled more perfectly to fit its immediate experiences, and more powerful to evolve hopeful suggestions for the immediate future. Sometimes, operating along the lines which I have indicated, the brain might arrive at new conclusions, not as matters of certainty, but in a form in which only the probability of truths were surmized. In other words, there might be a certain indefiniteness in the picture which was precipitated from the brain as a result of its meditations. Perhaps this situation is not without its counterpart even in our present-day thinking, where the mind frequently feels that it is very near the understanding of a certain phenomenon, but lacks complete conviction on account of certain imperfections which it is difficult to locate and which sometimes become located only after prolonged meditation.

And so, in the last analysis, we see all creation mirrored in mimicry in the brain—that strangest of all the creations of nature—a thing housed in a casket no larger than a child's toy, yet powered to be the recording place of all the doings of the universe—a thing daring to create a meaning to its own understanding of that great structure of which it itself is a part—a thing which can strike its tentacles of discovery into domains of which it has no previous experience—a thing which confines its business not to science alone, but which is the origin of our emotions, our joys, and our tears—a thing which can soften the brittle structure of philosophy with the balm of poetry—a thing which can command thoughts as of the thoughts of angels or can embroil itself in the villainies of hell—a thing which is perhaps the crowning peak of all nature's creations—the brain of man.

**Portable Drafting Machine.**—Because two young engineers experienced annoyance at the necessity of carrying rulers, protractors, T-squares and triangles into the field for routine sketches, Draftette was invented. This simple device, made of anodized aluminum, can cover an area of 11 in. × 17 in., yet fits snugly into a man's pocket. It is a precision instrument, all scales machine calibrated to 0.0005 of an inch, scientifically engineered to retain its original accuracy. Draftette clamps to drawing board or sketch pad in a jiffy.

Since no special training is required to operate, Draftette has met with approval, not only among engineers, draftsmen, artists and architects . . . but in the field of sales, interior decorating, and other businesses and professions, the pursuit of which require sketching away from the traditional drawing board. Students and do-it-yourself enthusiasts also find Draftette's versatility most helpful. It is priced considerably less than other drafting machines. Draftette is a mighty mite offering precision, versatility and convenience in one compact instrument that folds like a jackknife, and though it is featherlight in weight, is designed to withstand hard normal use. Draftette is a product of David Miller & Associates, Beverly Hills, Calif.

**One Man Helicopters.**—The model XRON–1 Rotorcycle is an ultra-small, one-man helicopter developed for the United States Navy. Designed, manufactured, and successfully test flown by the Gyrodyne Company of America, Inc., Saint James, Long Island, New York, the tiny craft was recently put through its paces for observers from the Navy's Bureau of Aeronautics. The midget helicopter, which weighs less than 500 lb. fully loaded with pilot, performs all basic helicopter maneuvers and cruises with great ease. Test reports indicate that the Rotorcycle has excellent control qualities at all speeds and its smoothness from the vibration standpoint is beyond expectation.

The Rotorcycle's intended use is for observation, liaison, and small unit tactical maneuvers. In addition, the requirements call for the Rotorcycle to require low training time, be simple to maintain, and to be adaptable to low cost production. The Rotorcycle is collapsible and can be folded into a small package for easy transportation. Another feature of the craft is that the basic design will accommodate different engines through the range of 40 to 70 hp.

**Stair Climbing Truck.**—Precision Equipment Co. (Chicago) announces production of an amazing new stair climbing truck which has been designed to fill the needs of countless firms who have found it necessary to drag loads over curbs and up and down stairways. This remarkable truck moves stock upstairs or to the basement, with ease. *E-Z Climber's* two rocker-arms act like an extra pair of wheels and keep the truck on a constant line for *friction-free travel.* It is of value also, in moving parts and partially completed goods to departments located on the different floors of factories. Its size and maneuverability make it ideally suited even where there are doorway and aisle limitations. The *E-Z Climber* is strongly built with a heavy 1-in. o.d. tubular steel frame, *electrically welded* for utmost rigidity, with curved cross members. The 9 in. × 14 in. nose-plate is of heavy $\frac{3}{16}$-in. steel. The unit has a reinforced base plate beam. The semi-pneumatic, 10 in. × 2.75 in., steel disc wheels are ideal even on rough surfaces. Load capacity is 600 lb.

# AN ELEMENTARY DERIVATION OF THE FORMULA FOR THE WINDAGE JUMP OF A SPINNING SHELL

BY

JAMES F. HEYDA [1]

## 1. INTRODUCTION

Beginning with the fundamental paper in 1920 by Fowler, Gallop, Lock and Richmond (1),[2] considerable research has been done on the problem of describing the behavior of a spinning shell in flight. A minor problem in the over-all picture but one, nevertheless, of considerable importance in the mathematics of airborne flexible gunnery, is that of projectile windage jump. The first analytical treatment of this phenomenon was given in 1943 by T. E. Sterne (2). Sterne used the equations of the actual trajectory of the spinning shell provided by FGLR and evaluated the asymptotic angular difference between the directions of the actual trajectory and the particle trajectory (that is, the trajectory described by the center of gravity of the shell assuming its yaw to be identically zero) to give him a measure of the windage jump. Thus an understanding of the paper by Sterne is incomplete without a detailed reading of the long and difficult paper by FGLR.

In the latter paper the angular motion of the axis of a spinning and yawing shell is shown to be approximately epicycloidal about the forward direction of its center of gravity. The motion is more closely described as the vector sum of two damped circular motions, the lower frequency one representing a steady precession of the axis and the higher frequency one a nutation of this motion. It is interesting to note that in Sterne's final result these frequencies do not appear although they play a decisive part in its derivation. This suggests that in so far as windage jump is concerned a derivation should be possible directly from the defining differential equations of motion of the shell. This indeed turns out to be the case.

## 2. FORCE SYSTEM ASSUMED

We shall assume a force system acting on the spinning shell equivalent to that implicit in the work of Sterne. This system consists of the gravitational force **W** and the total reaction of the air on the shell **R**. **W** acts at the center of gravity O and **R** at the center of pressure *P*. (See Fig. 1.) It is further assumed that **R** acts in the plane of the yaw $\delta$; its component in a direction opposite to the motion of O is then

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

the drag **D** while its component normal to this motion is the lift or cross-wind force **L**. The forces **D** and **L** acting at $P$ tend to overturn the projectile and are equivalent in this respect to the overturning moment **M**. In accordance with the usual assumptions the magnitudes $L$ and $M$ are represented by

$$L = \lambda \sin\delta, \quad \lambda = K_L \rho d^2 u^2 \tag{1}$$

$$M = \mu \sin\delta, \quad \mu = K_M \rho d^3 u^2, \tag{2}$$

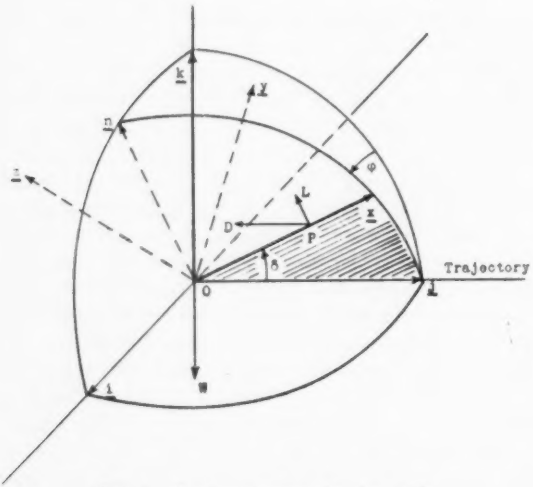


FIG. 1. Force system on spinning shell.

where $K_L$ and $K_M$ are the lift and overturning moment coefficients, respectively, $\rho$ is the air density, $d$ the shell diameter, and $u$ the velocity of point O.

In Fig. 1, **x** and **j** are unit vectors along the longitudinal axis of the shell and in the direction of motion of O, respectively. These vectors, separated by the yaw angle $\delta$, determine the plane of yaw (shown shaded). The unit vector **k** is directed normal to **j** in a plane containing the true vertical; finally, $\mathbf{i} = \mathbf{j} \times \mathbf{k}$. Angle $\varphi$ measures the angular orientation of the plane of yaw from the (**j**,**k**)-plane. The unit vector **y** is normal to the plane of yaw such that **x**, **j** and **y** form a $R - H$ set. The unit vector $\mathbf{x} \times \mathbf{y}$ will be denoted by **z**. We have then

$$\mathbf{L} = L\mathbf{j} \times \mathbf{y}, \tag{3}$$

$$\mathbf{M} = -M\mathbf{y}, \tag{4}$$

$$\mathbf{D} = -D\mathbf{j}. \tag{5}$$

Before proceeding to the derivation of the windage jump formula, we need an expression for the angular momentum $\mathbf{H}$ of the shell. Letting $A$ and $B$ denote the polar and transverse moments of inertia of the shell, $N$ its spin about $\mathbf{x}$ and $\boldsymbol{\omega}$ the angular velocity of $\mathbf{x}$, we can write

$$\mathbf{H} = AN\mathbf{x} + B\boldsymbol{\omega} \tag{6}$$

where

$$\boldsymbol{\omega} = -\dot{\delta}\mathbf{y} - \dot{\varphi}\sin\delta\mathbf{z}. \tag{7}$$

The expression (7) is obtained by noting that

$$\boldsymbol{\Omega} = \mathbf{x}(\boldsymbol{\Omega}\cdot\mathbf{x}) + \boldsymbol{\omega}, \tag{8}$$

where $\boldsymbol{\Omega}$ is the angular velocity of the $[\mathbf{x},\mathbf{y},\mathbf{z}]$-system of axes. Since

$$\boldsymbol{\Omega} = -\dot{\delta}\mathbf{y} + \dot{\varphi}\mathbf{j},$$

$$\mathbf{j} = \mathbf{x}\cos\delta - \mathbf{z}\sin\delta,$$

we have

$$\boldsymbol{\Omega} = \mathbf{x}(\dot{\varphi}\cos\delta) - \dot{\delta}\mathbf{y} - \mathbf{z}(\dot{\varphi}\sin\delta) \tag{9}$$

and (7) follows by comparing (8) and (9).

### 3. DERIVATION OF THE WINDAGE JUMP FORMULA

We consider the particle trajectory (that is, with $\delta \equiv 0$) and the actual trajectory simultaneously, denoting the velocity of the shell along the former by $\mathbf{u}_p$ and along the latter by $\mathbf{u} = u\mathbf{j}$. Neglecting the additional drag due to yaw, we shall also assume that

$$|\mathbf{u}_p| = |\mathbf{u}| = u. \tag{10}$$

For the particle trajectory, we have the equation of motion

$$m\frac{d}{dt}\mathbf{u}_p = -\frac{D}{u}\mathbf{u}_p + \mathbf{W}, \tag{11}$$

where $m$ is the mass of the shell.

For the actual trajectory, we have the equations

$$m\frac{d}{dt}\mathbf{u} = -\frac{D}{u}\mathbf{u} + \mathbf{W} + \mathbf{L} \tag{12}$$

$$\dot{\mathbf{H}} = \mathbf{M} \tag{13}$$

Since the windage jump is by definition the asymptotic angular separation of the two trajectories, we introduce the symbol $\mathbf{J}$, where

$$\mathbf{u} - \mathbf{u}_p = u\mathbf{J}. \tag{14}$$

An equation in **J** is obtained by subtracting (11) from (12). We find

$$u\frac{d\mathbf{J}}{dt} + \left(\dot{u} + \frac{D}{m}\right)\mathbf{J} = \frac{L}{m}. \tag{15}$$

If we ignore the effect of **W** on $\dot{u}_p$ (a likely assumption since aircraft gunfire trajectories are quite flat and the effect is approximately the same for both trajectories), we may write, scalarwise,

$$m\dot{u} \doteq -D \tag{16}$$

and hence rewrite (15) in view of this approximation as

$$u\dot{\mathbf{J}} = \frac{\mathbf{L}}{m}. \tag{17}$$

To proceed further we note that

$$\mathbf{L} = L\mathbf{j} \times \mathbf{y} = \lambda \mathbf{j} \times \mathbf{y} \sin\delta = \frac{\lambda}{\mu}\mathbf{M} \times \mathbf{j} = \frac{\lambda}{\mu}\dot{\mathbf{H}} \times \mathbf{j}.$$

If now we assume as Sterne did (2, p. 7) that "the inclination of the actual trajectory changes only slowly with the time," we may take, as a good approximation, $d\mathbf{j}/dt = 0$. From this it follows that

$$\mathbf{L} = \frac{\lambda}{\mu}\frac{d}{dt}(\mathbf{H} \times \mathbf{j}) \tag{18}$$

and hence

$$\frac{d\mathbf{J}}{dt} = \frac{\lambda}{m\mu u}\frac{d}{dt}(\mathbf{H} \times \mathbf{j}). \tag{19}$$

From (1) and (2) we note that

$$\frac{\lambda}{m\mu u} = \frac{K_L}{mK_M \cdot du}. \tag{20}$$

We integrate (19) regarding $K_L$, $K_M$, and $u$ as constant. (This is in keeping with the assumptions implied by Sterne in obtaining the equation at the bottom of p. 7 of reference 2.) Thus we find

$$\mathbf{J} = \frac{K_L}{mK_M \cdot du}[\mathbf{H} \times \mathbf{j} + \mathbf{C}], \tag{21}$$

where **C** is a vector constant. Employing the initial conditions

$$t = 0, \quad \mathbf{J} = 0, \quad \delta = \delta_0, \quad \dot{\delta} = \dot{\varphi} = 0, \tag{22}$$

we find

$$\mathbf{C} = -(\mathbf{H} \times \mathbf{j})_{t=0}$$

which, in view of (6) and (7), becomes

$$\mathbf{C} = -AN \sin\delta_0 \mathbf{y}_0, \tag{23}$$

where $\mathbf{y}_0 = \mathbf{y}|_{t=0}$ defines the initial position of the plane of yaw. Combining (21) and (23), we may write for the "non-steady-state" value of $\mathbf{J}$,

$$\mathbf{J} = \frac{K_L}{mK_M \cdot du}[\mathbf{H} \times \mathbf{j} - AN \sin\delta_0 \mathbf{y}_0]. \tag{24}$$

To obtain the windage jump or "steady-state" value of $\mathbf{J}$, denoted by $\mathbf{J}_{ss}$, we need to examine the asymptotic value of $\mathbf{H} \times \mathbf{j}$. Since

$$\mathbf{H} \times \mathbf{j} = AN \sin\delta \mathbf{y} - B(\dot{\delta}\mathbf{y} \times \mathbf{j} + \dot{\varphi} \sin\delta \cos\delta \mathbf{y}), \tag{25}$$

we observe that for projectiles, stable in the sense that the yaw is damped to zero during flight, the asymptotic value of $\mathbf{H} \times \mathbf{j}$ is zero.

Thus, the windage jump formula is

$$\mathbf{J}_{ss} = -\frac{AN}{md} \cdot \frac{K_L}{K_M} \cdot \frac{\sin\delta_0}{u} \cdot \mathbf{y}_0, \tag{26}$$

which agrees with that derived in (2). The scalar multiplier of $\mathbf{y}_0$ in (26) represents the magnitude of the windage jump angle. Furthermore, since $\mathbf{y}_0$ lies in the plane of this angle, we conclude, as a result of the definition (14), that the minus sign in (25) implies that the actual trajectory lies below the particle trajectory, the asymptotic angular separation of the two determining an angle whose plane is normal to the initial plane of yaw at the instant of fire.

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**Shock Tubes Create Speeds Exceeding 18,000 Miles per Hour and Heat Greater than Sun.**—Missile research with shock waves simulating flight problems at speeds exceeding 18,000 miles an hour is being conducted successfully at the Avco Research Laboratory, a unit of Avco Manufacturing Corporation's Advanced Development Division, at Everett, Mass.

The high speeds, accompanied by 15,000° F. temperatures—equal to 1½ times the heat at the surface of the sun—are achieved in several shock tubes, one of which is a large tube believed to be the biggest hypersonic research device of its kind. The research is being conducted for the Air Force. Information gained is being made available to other companies and is being used by them.

The Everett laboratory's big tube is a cannon-like assembly 100 ft. long. When it is fired, for the purpose of studying gases at extreme temperatures, a shock wave is created that races down the length of the tube, moving so fast that its travel time is measured in millionths of a second.

Dr. Arthur Kantrowitz, a leading scientist in gas dynamics, who is an Avco vice president and director of the Avco Research Laboratory, is in over-all charge of the shock tube research. The large tube, a distant relative of the wind tunnel, was designed and built by Avco for missile research.

The tube can be fired either by the high compression of a combination of gases or by the explosion of a combustible mixture of oxygen and hydrogen tempered by helium and nitrogen. In either case, the thick rear section, or driver, is loaded with gas under pressure and the rest of the tube, separated internally from the driver by a strong metal diaphragm, has almost all the air withdrawn from it. Then, when the driver reaches high pressure, either through mechanical pumping or the firing of combustible gases, the diaphragm bursts and the resulting shock wave speeds down the length of the four-inch diameter tube with camera and electronic instruments "watching" it.

Much of the shock tube research is done by studying the photographs of the wave made through a small window in the tube by an electronically-operated camera and also by studying the data recorded by instruments in the shock tube apparatus. The speeds simulated have exceeded 18,000 miles per hour, equivalent to about Mach 25, or 25 times the speed of sound. It is thus possible to study the interaction of satellites with the earth's atmosphere in this apparatus.

The big hypersonic tube is wheel-mounted so that part of the force of the firing can be absorbed by its own ponderous motion. Whenever one of the copper or steel diaphragms is burst, the whole tube rolls a short distance.

The fact that the tubes are in operation for only millionths of a second at a time requires high speed electronic instrumentation. However, if they were kept in operation for very much longer, the apparatus would melt and vaporize. Where extreme temperatures exist more than momentarily, such as on the sun, all matter is in a gaseous state.

# GRAPHICAL SOLUTION OF CERTAIN NONLINEAR DIFFERENTIAL-DIFFERENCE EQUATIONS *

BY

W. J. CUNNINGHAM [1]

ABSTRACT

A graphical method is described for obtaining solutions for differential-difference equations of the general form

$$\dot{x}(t) = f[x(t), x(t-\tau)],$$

where $\tau$ is a constant, and $f[x(t), x(t-\tau)]$ is a single-valued function which may be nonlinear. The method employs a construction on the $\dot{x}(t) - x(t)$ plane and leads to a solution similar to the phase-plane solution commonly used in studying pure differential equations of the second order. Besides giving the phase-plane curve, the construction also locates points known in time along this curve. The method is applied to two examples, both of which have been studied previously by approximate analytical methods and by the use of an analog computer. Solutions found by the construction are in excellent agreement with those found previously. The construction gives solutions for combinations of numerical values which cannot be handled by other methods.

A number of graphical methods have been devised for finding solutions for differential equations. All such methods basically apply to equations of the form $\dot{x} = f(x,t)$, where $\dot{x} = dx/dt$ and $f(x,t)$ is a single-valued function, with the possible exception of certain singular points where its value is not defined. The value of $\dot{x}$ can be interpreted as the slope of a solution curve plotted on the $x - t$ plane. Since the slope at any point can be found from the equation, it is not difficult to construct a solution curve starting at any specified initial point. A well-known process for carrying out the solution is the isocline method (**1**).[2]

A number of physical systems of interest are described by a second-order differential equation of the form $\ddot{x} = f(\dot{x},x)$ where $\ddot{x} = d^2x/dt^2$. This equation can be reduced to first order by the substitution $\ddot{x} = \dot{x}\, d\dot{x}/dx$ giving $d\dot{x}/dx = f(\dot{x},x)/\dot{x}$. Again, $f(\dot{x},x)/\dot{x}$ is single valued except at singularities (**2**). The isocline method can be used for finding a solution for this first-order equation. It gives a solution as a curve on the $\dot{x} - x$ plane, known as the phase plane. For a dynamical system, $x$ may represent a displacement, $\dot{x}$ the corresponding velocity, and $t$ the time. The phase plane then shows the variation of velocity with displacement, the parameter being time. A second integration is necessary to give $x$ as a function of $t$. This integration must be performed

* The work reported here was done under Contract Nonr-433(00) between Office of Naval Research and Yale University. The reproduction of this material in whole or in part is permitted for any purpose of the United States Government.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

in step-by-step fashion, using the relation $\Delta x = \dot{x}_{av}\Delta t$. Here, $\Delta x$ is the small increment in $x$ occurring in the corresponding increment $\Delta t$, and $\dot{x}_{av}$ is the average value of $\dot{x}$ during this interval.

The phase plane is a compact picture of the operation of a dynamical system, and presents considerable information in a small space. Probably for this reason it has been studied in detail, and graphical methods have been devised which lead directly to the desired solution curve without the necessity of carrying out all the steps of an isocline construction. One of the first of these short-cut methods is known by the name of Lienard (3,4). A generalization is the $\delta$-method (5) which can be applied to many equations of interest. Still other variations have been suggested (6,7,8).

All the foregoing methods have been devised to find solutions for pure differential equations. These equations have the common property that all terms are evaluated at the same value of $t$; all information is available at the same instant of time. There are physical systems of interest, however, that require description by differential-difference equations. A simple equation of this type has the form

$$\dot{x}(t) = f[x(t), x(t - \tau)], \tag{1}$$

where $\dot{x}(t)$ and $x(t)$ are evaluated at time $t$, while $x(t - \tau)$ is evaluated at the previous time $(t - \tau)$, with $\tau$ a constant. Again, $f[x(t), x(t - \tau)]$ is assumed to be single valued. The terms of Eq. 1 are not all evaluated at the same instant, and a new method of solution is required for this kind of equation. Instead of being able to find a unique solution from just a few initial conditions, as is the case with a differential equation, the value of $x(t)$ must be specified for the entire interval $-\tau \leq t \leq 0$ in order to obtain a unique solution for Eq. 1.

The term $x(t - \tau)$ can be expanded in an infinite Taylor series,

$$x(t - \tau) = x(t) - (\tau)\dot{x}(t) + (\tau^2/2)\ddot{x}(t) - (\tau^3/6)\dddot{x}(t) \cdots. \tag{2}$$

This series can be substituted into Eq. 1, and the result is a differential equation with all terms evaluated at $t$. This process shows that the differential-difference equation is equivalent to a pure differential equation of infinite order. An infinity of initial conditions is needed to give a unique solution. If the constant $\tau$, often interpreted as the delay time, is small enough, derivatives higher than the second can be omitted leaving only a second-order equation. This second-order equation can be solved by any of the usual methods. If $\tau$ is not sufficiently small, the differential-difference equation itself must be considered in any process of solution.

Because of general familiarity with the phase plane, it seems desirable to have any graphical solution for Eq. 1 lead to this diagram. The following process is somewhat like the isocline construction and produces a phase-plane curve on the $\dot{x} - x$ axes. During the construction, specific points in time are also located.

In order to begin, the value of $x(t)$ must be specified for the interval $-\tau \leq t \leq 0$. By appropriate differentiation, $\dot{x}(t)$ can also be found for this initial interval. A curve is then drawn on the phase plane, with $\dot{x}(t)$ as a function of $x(t)$ for this interval, as shown in Fig. 1. It is

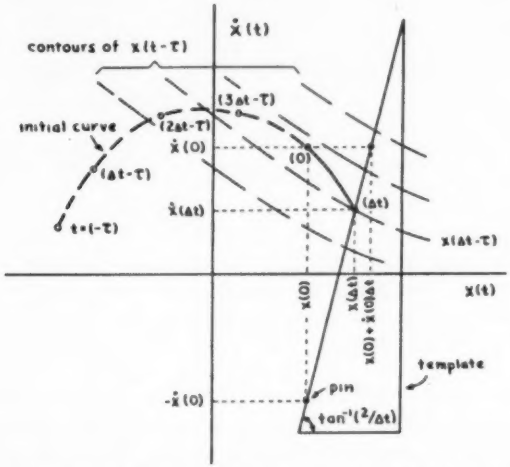


FIG. 1. Construction on phase plane showing extension of initial curve from point $[\dot{x}(0), x(0)]$ to point $[\dot{x}(\Delta t), x(\Delta t)]$.

necessary now to choose the increment $\Delta t$ for the steps in the succeeding construction. The size of this interval is subject to the usual compromises. If $\Delta t$ is too small, each step of the construction may have considerable accuracy, but many steps are needed and the cumulative error may be large; if $\Delta t$ is too large, each step is less accurate, but fewer total steps are needed. Moreover, it is convenient in the course of the construction to have $\Delta t$ be an integral submultiple of $\tau$. After $\Delta t$ is chosen, points corresponding to $(-\tau)$, $(\Delta t - \tau)$, $(2\Delta t - \tau)$, $\cdots$, 0, should be indicated on the initial curve for $\dot{x}$ vs. $x$. This is shown in Fig. 1, where $\Delta t$ has been chosen as $\tau/4$. At $t = 0$, the values are $\dot{x}(0)$ and $x(0)$.

In order to continue the solution curve, the next step is to find values $\dot{x}(\Delta t)$ and $x(\Delta t)$ existing at $t = \Delta t$. These values can be found by satisfying simultaneously two conditions. The first condition is given by the differential-difference equation itself, $\dot{x}(t) = f[x(t), x(t-\tau)]$. The most convenient way to use this equation is to construct contours on the $\dot{x}(t) - x(t)$ plane, with the parameter being $x(t-\tau)$. A sequence of numerical values can be assigned to $x(t-\tau)$ and corresponding pairs of values for $\dot{x}(t)$ and $x(t)$ calculated from the equation. From these data, contours can be drawn as shown in Fig. 1. The value of $\dot{x}(t)$ and $x(t)$ at any instant $t$ must lie on the contour for

that value of $x(t - \tau)$ existing at the previous instant $(t - \tau)$. This value is known from the way the solution is built up.

The second condition which must be satisfied is the integration over one increment, given by the relation

$$\Delta x = \dot{x}_{av}\Delta t. \tag{3}$$

For the interval $\Delta t$ during which $x$ changes from $x(0)$ to $x(\Delta t)$, approximately

$$\dot{x}_{av} = \dot{x}(0) + \Delta\dot{x}/2,$$

where $\Delta\dot{x}$ is the corresponding change in $\dot{x}$. Thus, Eq. 3 becomes

$$\Delta x = \dot{x}(0)\Delta t + (\Delta t/2)\Delta\dot{x}. \tag{4}$$

At the given point, $\dot{x}(0)$ and $\Delta t$ are constants, so that $\Delta x$ is a linear function of $\Delta\dot{x}$. The point on the solution curve at $t = \Delta t$ must lie somewhere on the straight line representing Eq. 4. This line can be easily located by two points. One point is found by letting $\Delta x = 0$, so that $x = x(0)$, $\Delta\dot{x} = -2\dot{x}(0)$, and $\dot{x} = -\dot{x}(0)$. The second point is located by letting $\Delta\dot{x} = 0$, so that $\dot{x} = \dot{x}(0)$, $\Delta x = \dot{x}(0)\Delta t$, and $x = x(0) + \dot{x}(0)\Delta t$. These two points are shown in Fig. 1, together with the straight line drawn through them. The slope of this line is $2\dot{x}(0)/\dot{x}(0)\Delta t = (2/\Delta t)$ and is a constant so long as $\Delta t$ is unchanged.

In carrying out an extended solution for a given equation, many of these lines must be located. Since, with $\Delta t$ fixed, all lines have the same slope, it is convenient to construct a template in the form of a right triangle having as one angle, $\tan^{-1}(2/\Delta t)$. Then, when solution has proceeded to a point such as $[\dot{x}(0), x(0)]$, the next construction line is readily found as follows. The point $[-\dot{x}(0), x(0)]$ is located on the paper and a pin is inserted there. The triangular template is placed against the pin, its sides aligned with the $\dot{x} - x$ axes, and the line drawn as shown in Fig. 1.[8]

Finally, then, the extension of the solution curve from the point $[\dot{x}(0), x(0)]$ to the point $[\dot{x}(\Delta t), x(\Delta t)]$ is completed as shown in Fig. 1. The second point is located on the contour for $x(\Delta t - \tau)$. The particular location on this contour is found at the intersection with the construction line drawn with slope $(2/\Delta t)$ through the point $[-\dot{x}(0), x(0)]$. After the point at $t = \Delta t$ is found, the next point at $t = 2\Delta t$ is determined in exactly the same way, and construction proceeds as far as desired. The result is a series of points separated by increments $\Delta t$ in $t$. A smooth curve drawn through these points represents the solution curve for the original equation. Information can be taken

[8] This simple construction, making use of a template of angle $\tan^{-1}(2/\Delta t)$, is useful in locating points separated $\Delta t$ in time along a phase-plane curve obtained by any standard method for solving a differential equation graphically. It is simpler than either numerical integration using Eq. 3, or measurement of a small angle as described in references 5 and 8.

directly from this curve for plotting curves of $\dot{x}$ vs. $t$ or $x$ vs. $t$ without additional integration.

The most laborious part of this method of solution is the calculation and plotting of the contours for specific values of $x(t - \tau)$. This process is analogous to the plotting of the directed line segments of appropriate slope used in the isocline method of solution. Once the contours have been plotted, the remaining steps of the solution can be carried out rapidly and easily. Not only is the phase-plane curve obtained, but points in time are located along this curve.

Various minor modifications apply here as to any graphical process. If the range of numerical values of $\dot{x}$ and $x$ is large, it may be desirable to use two sets of axes in the process. One set applies to large values and the other to small values, and transition is made from one to the other at appropriate points in the solution. Also, it may be desirable to change the size of increment $\Delta t$ in the course of the solution, using a small value in regions of rapid change and a larger value when changes take place more slowly. If $\Delta t$ is changed, construction proceeds exactly as described, except the slope of the construction line, $(2/\Delta t)$, must be modified to suit.

It is worthwhile to point out a significant difference between the phase-plane diagrams for a pure differential equation and a differential-difference equation. For the pure differential equation, the slope of the solution curve $d\dot{x}/dx$ at any point on the phase plane depends only upon the values of $\dot{x}$ and $x$ existing at that point. Because of this property of unique slope, only one solution curve passes through any point and two solution curves never intersect. This statement is true except at certain singular points where the slope is undefined. These singularities are points of equilibrium of a dynamical system, and an infinity of solution curves may come together at such a singularity.

For a differential-difference equation, the slope of the solution curve $d\dot{x}(t)/dx(t)$ depends upon $x(t - \tau)$ as well as upon $\dot{x}(t)$ and $x(t)$. The slope does not have a unique value at a given point on the phase plane, since the given point specifies only $\dot{x}(t)$ and $x(t)$, but not $x(t - \tau)$. It is possible, therefore, for several solution curves for the differential-difference equation to intersect, or for a single solution curve to return and cross over itself. Certain choices of $x(t)$ for the initial interval may allow this phenomenon to occur, and it is illustrated in several of the accompanying examples.

A further observation about the specification of $x(t)$ for the initial interval may be made. Presumably this choice can be made freely with no restrictions. On the other hand, some equations lead to solutions which very rapidly assume a steady state. If the initial specification of $x(t)$ differs considerably from the steady-state condition, there may be a rather abrupt transition in the brief interval just following $t = 0$. This is also illustrated in an example.

Two examples are now given of the application of the graphical method just described to specific problems. Both these problems have been investigated previously by approximate analytical methods and by the use of an analog computer. Solutions found by the graphical method agree very well with those already obtained in other ways.

The first example is an equation of growth,

$$\dot{x}(t) = [a - bx(t - \tau)]x(t), \tag{5}$$

where $a$, $b$, and $\tau$ are constants. This equation arose in an attempt to describe the population of a colony of biological organisms (9,10). A solution obtained by the graphical method is shown in Fig. 2.

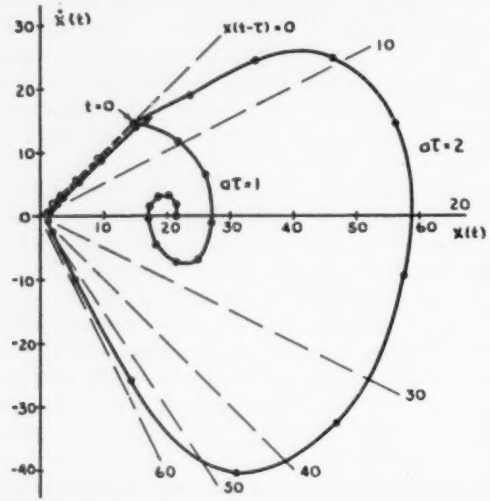


FIG. 2. Solutions for two cases of Eq. 5. Indicated points are separated $\Delta t = 0.5$. If $a\tau = 1$, solution is a damped oscillation; if $a\tau = 2$, solution is a periodic oscillation.

It has been shown that product $a\tau$ is important in determining qualitative properties of the solution, while the ultimate mean value of the solution is ratio $a/b$. For this example, values are assumed as $a = 1$, $b = 1/20$, so that $a/b = 20$, and $\Delta t = 0.5$. Construction is shown for two values of $\tau$: $\tau = 1$, giving $a\tau = 1$; and $\tau = 2$, giving $a\tau = 2$. If $x$ is initially so small that $x \ll a/b$, $x(t)$ is approximately of the form $x = C\exp(at)$ where $C$ is a constant. For the initial interval in the figure, it is assumed that $x = 2\exp(t + 2)$, so that $\dot{x} = 2\exp(t + 2)$. The initial curve is plotted from these relations, and solution proceeds as described previously with points separated $\Delta t$ in time being indicated. The value $a\tau = 1$ leads to a damped

oscillation about $x = a/b$. The value $a\tau = 2$ gives a periodic oscillation described by the formation of a closed curve, or limit cycle.

A second example is the equation of an oscillator,

$$\dot{x}(t) + ax(t) - aC_0(1 + h)x(t - \tau) + g[ax^3(t) + 3x^2(t)\dot{x}(t)] = 0, \quad (6)$$

where $a$, $C_0$, $g$, $h$, and $\tau$ are constants. This equation applies to an oscillator made up of a limiting low-pass amplifier combined with a feedback loop having constant time delay (11). Two sets of numerical values are considered here. In each case, it is assumed that $a = 0$, $aC_0 = -0.785$, $g = 8.4 \times 10^{-5}$, $\tau = 2$, and $\Delta t = 0.5$. Actually, where rapid changes occur, a smaller value of $\Delta t$ is needed for good accuracy. The fact that $a = 0$, although product $aC_0$ is not zero, simplifies the example somewhat, although the same general construction applies if $a$ is not zero.

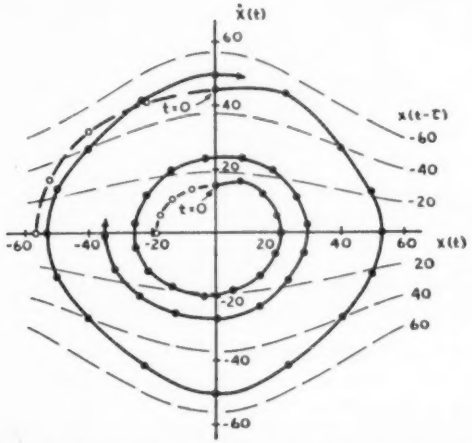


FIG. 3. Solutions for Eq. 6 for $h = 0.2$ with two initial curves. In each case the solution curve ultimately approaches the same limit cycle, characteristic of a nearly-sinusoidal oscillation. Indicated points are separated $\Delta t = 0.5$.

For the first case, shown in Fig. 3, it is assumed that $h = 0.2$, a case that has been treated analytically. It was shown that these parameters lead to a steady-state solution of the form $x = U \sin\omega t$, where in general $U = (4h/3g)^{\frac{1}{2}}$ and the present numerical values give $\omega\tau = \pi/2$. Thus, here $\omega = \pi/4$ and $U = 57$, so that $x = 57 \sin(0.79t)$. This relation is used for constructing the initial curve for the outer solution of Fig. 3. The solution curve quickly assumes the limit cycle of a steady-state periodic oscillation. The distorted elliptical shape, with $\dot{x}$ abnormally large near $x = 0$, indicates the oscillation is approximately sinuosidal but with flattened peaks. The inner curve of Fig. 3 is obtained if

initially $x = 19 \sin(0.79t)$. This curve spirals gradually outward, indicating the relatively slow growth of amplitude of oscillation associated with a small value of parameter $h$.

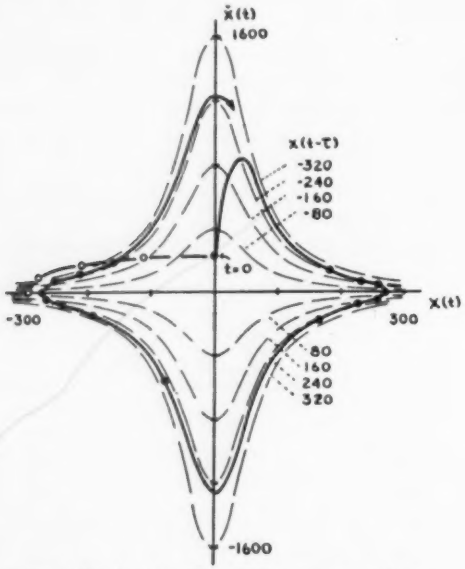


FIG. 4. Solution for Eq. 6 for $h = 5.4$. The solution curve quickly assumes the limit cycle characteristic of a relaxation oscillation. Indicated points are separated $\Delta t = 0.5$.

The second case, shown in Fig. 4, is obtained if $h = 5.4$ so that $aC_0(1 + h) = -5$. Analytical methods used previously fail for so large a value of $h$, since these methods require that $h \ll 1$. Because of the very large values of $\dot{x}$ that are reached during the solution, the numerical scale along the vertical axis of Fig. 4 is compressed with respect to that on the horizontal axis. For lack of a better condition, construction is started using the same relation for $x$ as in Fig. 3, but here with $U = 295$. The solution curve almost immediately becomes a limit cycle, this time having an irregular shape. The peak values for $x$ turn out to be near the value $U$, and the limit cycle follows closely the contours of $x(t - \tau) = \pm U$ as $x$ makes the transition between $\pm U$. This can be interpreted as a kind of relaxation oscillation with sudden transitions between considerably flattened peaks.

Finally, this case of Eq. 6 with $a = 0$ can be simplified by introducing a new variable $y(t)$ defined so that $\dot{y}(t) = x(t)$. Upon making this change, a new equation, equivalent to Eq. 6, is found as

$$\ddot{y}(t) - aC_0(1 + h)y(t - \tau) + g\dot{y}^3(t) = 0. \tag{7}$$

Here, $y(t-\tau)$ is related only to $\dot{y}(t)$. This change is analogous to that used in converting van der Pol's equation to Rayleigh's equation (4, p. 124). A construction based on Eq. 7 is shown in Fig. 5, with

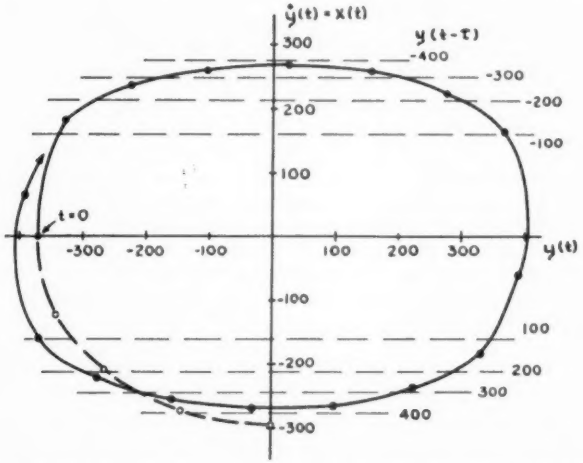


FIG. 5. Solution for Eq. 7 analogous to Eq. 6. This figure is equivalent to Fig. 4, but is obviously simpler to construct. Indicated points are separated $\Delta t = 0.5$.

the same numerical parameters as used in Fig. 4. It is obvious that both the numerical and graphical work associated with Fig. 5 are much simpler than that of Fig. 4. The resulting variation of $x$ with $t$, obtained from the two figures, is in good agreement, however.

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**TV Tape Recording System.**—Color television programs can now be recorded on magnetic tape and rebroadcast over standard commercial broadcast facilities, with up to 15 minutes of programming stored on a single 20-in. reel of tape, scientists of the Radio Corporation of America reported at the National Convention of the Institute of Radio Engineers.

Full engineering details of the RCA television tape recorder were disclosed by Dr. Harry F. Olson, Director of the Acoustical and Electromechanical Research Laboratory, RCA Laboratories, and five members of the development team at RCA's David Sarnoff Research Center, Princeton, N. J.

Their reports told of improvements which have been made in the system since its first demonstration in December, 1953, and included these points:

1. Programs recorded on the magnetic tape can be erased, and the tape re-used at least 100 times without perceptible deterioration;

2. Tape-recording programs can be stored for months with no loss in quality;

3. An ingenious system has been designed to regulate tape speed automatically during playback with extreme precision—on the order of one-50 millionth of an inch per second—to eliminate irregularities which might cause the television picture to jump perceptibly on the viewing screen;

4. The system employs seven different tracks in the half-inch width of the magnetic tape to carry six different types of information. These record the separate electrical signals for the red, green and blue portions of the color television picture, the high-frequency components of the color signals, a synchronizing signal to ensure proper relationship among the various elements of the transmitted picture, and, on two tracks, the signals for the sound portion of the telecast.

"The RCA magnetic tape recorder for television was developed to achieve a swift, economical and efficient means of recording color television programs for storage, playback, or rebroadcast," said Dr. Olson. "It is capable of receiving and recording broadcast programs or of recording directly from cameras in a TV studio. The potentialities of the system were demonstrated last year when a color program recorded on magnetic tape several days in advance was transmitted over commercial network facilities of the National Broadcasting Company between New York and Saint Paul, Minnesota. The advantages of tape recording include the absence of chemical processing required for film, the ability to play back recorded material immediately if desired, and re-use of the tape . . .

"The system operates on these principles. Electrical signals—the broadcast video and audio signals of television—are impressed through a recording head onto the magnetically treated surface of a plastic tape. As the tape is drawn across the recording head, the head continuously changes the magnetic condition of the magnetic particles on the tape, forming a compact code of the original signal. This magnetic pattern will remain indefinitely on the tape during repeated playbacks, until it is desired to 'erase' it electronically and use the tape again to receive and store another set of signals. In playing back the recorded program, the tape is moved across the magnetic head: the magnetic code on the tape causes an alternating current to flow in the windings around the head, creating a duplicate of the original recorded signal."

# EXPERIMENTAL VERIFICATION OF CIRCULAR PLATE BENDING THEORY

BY

JACOB HERRMANN [1] AND C. S. ADES [1]

ABSTRACT

This paper describes an experimental investigation involving two circular ring plates under a concentrated load along the inner edge and freely supported along the outer edge. The thickness of one plate was uniform, while that of the other decreased linearly from the bore to the rim. Strain measurements were taken at various radii to check the elementary elastic bending theory as applied to plates with both uniform and non-uniform profiles. Later, the disks were loaded to virtual failure as indicated by excessive deflections in order to determine their rupture factors. Finally, to evaluate the ultimate tensile strength needed for calculating those factors, a hardness check was made on just the uniform plate.

## PURPOSE OF THE EXPERIMENT

The chief object of the tests was to verify the common elementary thin plate elastic bending theory (1, 2).[2] In the case of the disk of conical profile, the solution for concentrated edge load was obtained through the numerical integration of the differential equation for non-uniform circular plates under that type of loading derived by the method outlined in (1). A process in closed form adapted to this particular profile is available in (3), where Poisson's ratio is restricted to the value $\frac{1}{3}$. In the present solution, this was taken as 0.3. The value of Young's modulus was assumed to be $30 \cdot 10^6$ psi.

Another object of the tests was to evaluate the rupture factors (4) for the two disk designs. A comparison of those factors would then give an indication concerning the reliability of the relative weight saving of the tapered versus the uniform design as predicted by elastic theory for the loading and the edge conditions considered.

## TEST SPECIMENS

The two plates tested were circular ring plates with an inside radius of 2 in. and an outside radius of 10 in. The uniform disk was 1 in. thick, while the other had a straight taper running from a thickness of 1 in. at the inner edge to $\frac{1}{4}$ in. at the outer edge. Both were made from the same heat of SAE 8740 steel.

## TEST PROCEDURE

An Olsen machine was used to test the disks. Figure 1 shows the uniform plate under test. The plates were loaded as indicated in Figs.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

2 and 3 with no edge fixity. In each case the load, and likewise the reaction, was applied along a circular ring extending ½ in. from the edge involved.

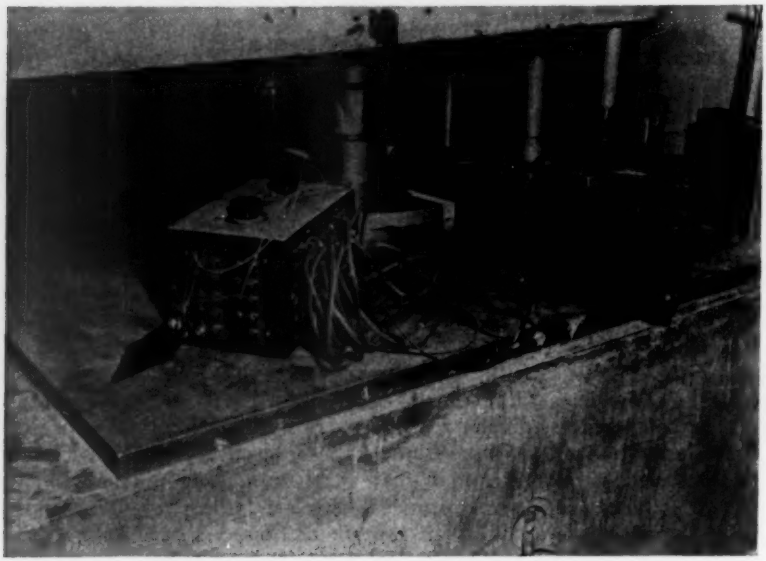

FIG. 1. Uniform plate under test.

The hoop and radial strain gages were placed on the lower face of each plate along radial lines 180° apart. The gages used were Baldwin-Lima-Hamilton SR4 strain gages. The innermost hoop gage on each disk was an A–7 gage; all the other gages were of the A–5 type. In the case of the uniform plate, readings were taken at 10,000-lb. increments of load up to 90,000 lb.; and for the tapered plate, they were taken at 7500-lb. increments up to 60,000 lb. An inspection of our load–strain plots—not shown—indicates that all strains measured on the uniform plate were within the elastic range. In the case of the tapered plate, only the readings up to 30,000-lb. load were actually used, in order to keep definitely within the elastic range on that one also.

## RESULTS AND CONCLUSIONS

Comparisons of the computed hoop and radial strains with the values found by test are shown on Figs. 2 and 3. In the case of the uniform plate, a solution was made for the actual partially distributed load condition, as well as for the concentrated edge load condition. This refinement resulted in a definite improvement in the computed curve

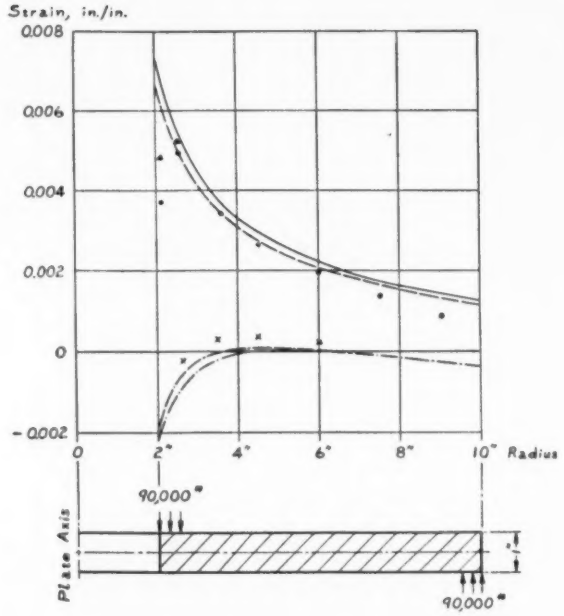


FIG. 2. Results from test of uniform plate.

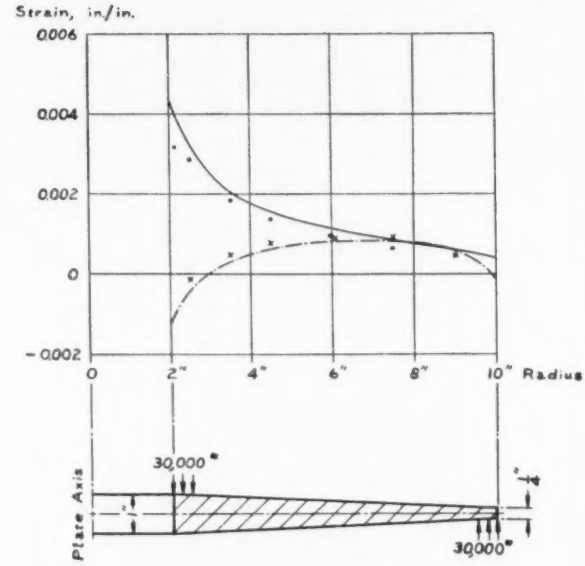


FIG. 3. Results from test of tapered plate.

and would undoubtedly bring about a similar improvement for the tapered plate, if applied to it. In the case of the two inner hoop gages on the uniform plate, the instantaneous strain rate gradually decreased as the load was increased. The only plausible explanation seems to be that this was caused by the outward shifting of the load as applied by the loading capsule when deflection began and steadily increased. Two values for each of those hoop strains are plotted on Fig. 2; quite naturally, the pair corresponding with the initial strain rates shows the better agreement with the predicted curves.

Except for the hoop strains near the load and near the reaction, the agreement between test and theory appears to be very good; this local effect, however, may call for further study. It is probably to quite some extent due to the fact that normal stresses across planes parallel to the neutral surface are neglected in the Poisson theory for the bending of plates. A similar effect was found elsewhere (5) in the photoelastic check of a plate continuous to the center and freely supported very near the rim. There the load was transmitted to the plate by a centrally placed loading ring with an outside diameter only one-sixteenth as great as that of the plate itself. Measurements were taken along each of four radial lines; the measured hoop and radial bending moments just outside the loading zone averaged about 4 per cent less than the predicted values. Some of the percentage discrepancies between our predicted and measured hoop strains were considerably greater than that; but it should be kept in mind that the innermost hoop gage on each of our plates was actually placed directly below the load.

The critical stress is the bore hoop stress. Its computed value at 100,000-lb. concentrated load was 242,000 psi. for the uniform plate and 436,000 psi. for the tapered plate. The volumes were 301.6 cu. in. and 163.4 cu. in., respectively. Since the stresses vary inversely with the square of an over-all magnification factor applied to the thickness, the computed relative weight saving when using the tapered plate under the stated conditions is

$$\text{R.W.S.} = 1 - \frac{163.4}{301.6}\sqrt{\frac{436{,}000}{242{,}000}} = 27\%.$$

The Brinell hardness test of the uniform plate indicated an ultimate tensile strength of 163,000 psi., and this was assumed to apply for the tapered plate as well. The ultimate loads as indicated by excessive deflections were 253,000 lb. and 144,000 lb. for the uniform plate and the tapered plate, respectively. The corresponding rupture factors, or ratios of actual to calculated ultimate loads, were 3.75 and 3.85, respectively. Since these do not differ much, the weight saving of 27 per cent with the tapered plate as calculated by the elastic theory is very nearly correct.

*Acknowledgment*

The office work required for this project was done in the Shock Strut Department of the Bendix Products Division, and the test work was carried out in its Research Laboratory. We acknowledge our indebtedness to Mr. W. E. Eldred, Engineering Manager, for his permission to publish this paper and to Mr. J. L. Edman, Chief Technical Engineer of Airframe Components, for his consultation. Mr. T. C. Delker, Chief Engineer of the Shock Strut Department, helped expedite the laboratory work. We also take this opportunity to express our thanks to Mr. R. W. Jordan, Laboratory Technician, for his assistance in carrying out the tests.

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**Medical Color TV Systems.**—Development of commercial color television has brought benefits to medicine and dentistry by encouraging parallel development of specialized color TV equipment for medical and surgical uses, Leslie E. Flory, scientist of RCA, said at the annual meeting of the American Association of Dental Schools.

Mr. Flory, who played a leading part in development of RCA's new color TV system for medical application, emphasized the importance of color added to the television medium in communicating medical and dental information.

"A decision must often be made on the basis of a rather subtle color shading on a piece of tissue or a microscope slide," he said. "Equipment designed for the broadcast of entertainment, while satisfactory from an operational standpoint, was not designed for these specialized applications and so is inclined to be more bulky and complicated than need be for medical and dental use.

"This rightly indicates the use of equipment specially designed for the purpose. However, the development of color broadcasting is an important factor in the parallel development of specialized medical equipment. Millions of dollars have been and are being spent in the development of a color service based on broadcast standards. This means that terminal equipment, monitors, relays, and—most important—home type receivers, will be available at a reasonable price due to large production. So it is of great importance that any specialized equipment be designed within the framework of these standards."

Mr. Flory pointed out that RCA's development work had therefore been directed toward a complete color system based on the Vidicon camera tube which is used in present medical and industrial black-and-white TV systems, and operating on the same compatible standards as commercial color television. Use of the Vidicon, he said, permitted the design of more compact equipment which is simple to operate and suitable for use in the operating room with the illumination normally used by surgeons.

Mr. Flory's talk concluded with a demonstration of RCA medical color TV system, which was developed at the David Sarnoff Research Center of RCA, Princeton, N. J. The entire system comprises a 3-Vidicon color camera and four packaged units weighing about 40 lbs. each.

**Scintillation Counter with Built-in Loudspeaker Alarm.**—A brand new scintillation counter (Gardiner Electronics model 143) has been placed on the market with a built-in loudspeaker alarm. It is believed to be the first of its kind. The loudspeaker starts giving out a tone when a preset gamma radiation level is reached and increases in pitch proportionally when this level is exceeded. It also has provisions for headphones for use while flying or using in a noisy place. It also features a built-in battery tester that individually tests each battery in a few seconds. It has an 8 range sensitivity switch covering the ranges 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1, and 5 MR/HR and time constants of 0.2, 0.5, 1, 5, and 25 seconds. It uses a thallium activated sodium iodide crystal size $1\frac{1}{2}$ in. $\times$ 1 in. All of the tubes are of the plug-in type and most of them are obtainable at all radio stores.

# PIONEER BIOCHEMICAL RESEARCHES AT THE UNIVERSITY OF PENNSYLVANIA *

BY

JOSEPH SAMUEL HEPBURN [1]

Benjamin Franklin (1)[2] had included among the texts for his proposed Academy "*Arbuthnot* on Air and *Aliment*, *Sanctorius* on Perspiration, *Lemery* on Foods." These titles suggest the modern sciences of biological chemistry and bromatology. After the Academy had been organized and had become the College of Philadelphia, it instituted the first medical school in English-speaking North America in 1765. John Morgan (2), its first professor of the theory and practice of physic (medicine), also gave the instruction in chemistry for four sessions (1765–1769); then Benjamin Rush became the first incumbent of an American professorship devoted exclusively to chemistry. The chemical lectures of Morgan have been preserved and contain items of a biochemical nature, such as the role of water in the nutrition of plants, the occurrence of iron in the human body, of muriatic acid (chlorides) in the tissues of plants and animals and in the urine, and of fixed or mephitic air (carbon dioxide) in urinary calculi. John Archer received the first medical degree in course, conferred in English-speaking America, Bachelor of Medicine from the College of Philadelphia in 1768. His notebook as a medical student signed by him on January 27, 1767 has recently been presented to the University of Pennsylvania. Of the 226 manuscript pages, fourteen are devoted to the urine, normal and pathological, including color, quantity, odor, taste, fluidity (concentration), sediment, and influence of drugs. Mention is made of the occurrence in urine of common salt and of microcosmic salt (sodium ammonium hydrogen phosphate). This instruction in chemistry gave rise to biochemical research in the preparation of dissertations for degrees in medicine, especially by the pupils of James Woodhouse[3] during the closing decade of the eighteenth century and the opening decade of the nineteenth century. Unfortunately these researches, though published, were overlooked by Chittenden (3) when he wrote "The first definitive laboratory of

* Presented before the City History Society of Philadelphia, February 15, 1955.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

[3] James Woodhouse has been mentioned as the custodian of Franklin's Electrical Machine in the first article in this series "How Franklin's Electrical Machine came to The Franklin Institute." In that article a concise account of his scientific and educational activities has been given.

physiological chemistry in America was established in the Sheffield Scientific School at Yale University in 1874."

While the interest of Woodhouse (**4, 5, 6**) and his associates in the institution, which meanwhile had become the University of Pennsylvania, was primarily from the aspect of physiology and therapeutics, they also studied chemical constituents. Miles (**7, 8**) and other writers have noted the interest of the Chemical Society of Philadelphia in the development of the natural resources of the United States, for example, by analyses of native ores and minerals, and by the request of Thomas P. Smith in his will bequeathing to the American Philosophical Society his minerals and the journals of his tour of inspection in 1800–1802 of European industries, especially chemical: "Should they find any information therein contained useful to the manufactories of my country, I beg them to publish them." This interest in the development of the natural resources was shared by the members who worked in the field of biochemistry, and, at times, suggested new industrial uses, usually chemical, for the materials with which they worked.

In the research reported in his dissertation (**9**), John Penington[4] tested the coagulable lymph of the blood for the presence of sugar by boiling with strong nitrous (nitric) acid. On cooling, crystals deposited which reacted with lime water to form a precipitate "in the same manner as the acid of sugar does." The researches of Scheele (**10**) a few years before had shown the identity of the acid of sugar and the acid of sorrel, now called oxalic acid. Thus Penington was an early research worker on the occurrence of sugar in the blood. For his dissertation Penington studied also the fermentation of sugar to alcohol, then to vinegar (acetic acid), and attributed the transformation of alcohol to vinegar to loss of phlogiston. He also used a mixture of "the salt formed by the fossil alkali and fixed air" (a sodium carbonate) and "marine acid, commonly called spirit of sea-salt" (hydrochloric acid) as a leavening agent in breadmaking; thus was a pioneer in the researches which finally produced modern baking powder. According to Hart (**11**) the first patent for baking powder was based on this chemical reaction. This British Patent No. 7076 was issued to John Whiting, M.D., and inrolled November 3, 1836.

James Woodhouse[5] studied the persimmon (**6**). He isolated from the juice of the unripe fruit a gum resin which yielded a purple color with green vitriol (ferrous sulfate). To ascertain whether this gum, after its ingestion, passed into the circulation or into the urine unaltered, he swallowed six ounces of a strong infusion of the gum diluted with a half-pint of water. The urine was collected at intervals; and blood was drawn from a vein in the arm. The urine and the blood

[4] John Penington and his work have been mentioned in the second article of this series "The Chemical Society of Philadelphia and Certain Local Institutions."

[5] See footnote 3.

serum were tested with ferrous sulfate, and yielded a negative reaction for the gum. Woodhouse mentions the therapeutic use of the persimmon, and its possible use as a tanning material, a dyestuff, and in the manufacture of ink, beer, spirit, and bread.

Samuel Cooper (12) studied the action of various preparations of the common thorn apple (Jimson weed) on man when ingested, injected into the urethra, applied to the eye or the skin. Rats, frogs, and dogs were also used; and the procedures included intravenous, intra-abdominal, and rectal injection, application to the eye, and to the exposed heart and brain. He summarized the action as: inflammation of the eye, dilatation of its pupil, increased cardiac action, intoxication, mania, convulsions, effusion in the brain. This comment describes a person who had ingested 2 grains of the leaves diffused in water: "he resembles a person laboring under the effects of too much spiritous potation."

Thomas Horsfield (13) reported that the active principal of poison-ash (swamp sumac), poison vine (poison ivy), and common sumac is resident in the juice. He studied in detail the symptoms, chiefly cutaneous, of the poisoning, and its treatment. When juice of the swamp sumac was applied to the back of the hand, a vesicle was produced. When persons subject to poisoning by this plant were inoculated with the serous fluid in this vesicle, poisoning did not develop. On the economic side, Horsfield described the preparation of ink from leaves of common sumac, and recommended these leaves for tanning leather. He found that flannel and silk could be dyed with the leaves and certain other parts of all three species. An infusion of the leaves of common sumac and of swamp sumac underwent alcoholic fermentation. An infusion of the leaves of poison ivy or of the berries of common sumac was suggested as a source for the production of vinegar.

Edward Brailsford (14) made an extensive study of tobacco, and its preparations. He reported that ingestion of either the infusion or decoction of tobacco produced nausea, increased pulse rate, perspiration, and dizziness. Squeezing the boiled leaves with the hands, or their application to the skin of the inner thigh produced nausea and headaches. Mice were killed by oral, rectal, or intraperitoneal administration of the decoction. Other experiments were made on dogs, cats, pigeons, frogs, and earth worms.

John Moore (15) studied the action of ingested digitalis on man in health and in disease.

John Church (16) devoted his dissertation to a plant product, camphor. Some plants (daffodil, lily, hyacinth, crocus) but not all plants thrived more in water impregnated with camphor. In man, ingestion of 10–20 grains produced perspiration, and an increase in pulse rate and secretion of urine. Church also used cats and dogs.

Inflammation was produced by oral administration of 10–15 grains, or by use of an aqueous suspension, instilled into the orbit, or injected subcutaneously or intra-abdominally. A cat was killed by 15 grains of powdered camphor by mouth, kittens by 10 grains by mouth, or by 60 drops of camphor water by mouth. The aqueous suspension first stimulated, then paralyzed frogs. Church designated camphor as a stimulant, easily and suddenly exhausted. He also described a camphor addict.

John Redman Coxe[6] made this interesting biochemical observation (17) concerning the gas in the air space between the inner and outer shell membranes at one end of the hen's egg: "Experiments made by myself and others prove that portion of air which we always find in one end of the egg, to be oxygenous gas,—and that it is vitiated, in proportion as the chick arrives to maturity."

Adam Seybert (18) concluded that, although the blood or other animal matter may be excited into a putrid fermentation out of the body by the addition of a putrid ferment, yet such a process cannot be excited in the living body. Since volatile "alcali" (ammonia) is one of the characteristic products of putrefaction, vegetable blue paper was used as a reagent to detect the presence of "any alcaline salt" in the serum of the experimental animals (dogs). The specific vegetable blue is not defined. However a "Dictionary of Chemistry" published in London in 1771 mentions that the blue color of many flowers may be extracted by infusion in water, is changed by acids to red, and by alkalies and lime water to green which afterwards becomes yellow. Such an indicator, red cabbage, is described by Cohn (19) who states that the comminuted leaves of red cabbage, on exhaustion with water or dilute alcohol, yield a violet solution which is changed to red by acids, to green by alkalies, and is quite sensitive to ammonia. The blue color of Seybert's indicator was not changed by serum of dogs subjected to the following procedures: (*a*) Normal, (*b*) Starved for 17 days, (*c*) Fed highly putrid beef for 26 days, (*d*) Fed highly putrid broth for 3 days, (*e*) Injected intravenously at intervals with putrid blood in increasing doses (6, 12 grains, $\frac{1}{2}$, 1 drachm). In group (*e*) symptoms were produced; and death occurred after the last (maximum) dose. The reaction of the urine to the indicator was unaltered. When highly putrid food (broth or beef) was fed to a dog, the putrid odor was markedly diminished or entirely absent from the gastric contents 3–3$\frac{1}{2}$ hours later.

Seybert also conducted experiments on the detoxifying mechanism and the buffering power of the animal body. Intravenous injection into dogs of an aqueous solution containing 15–45 grains "mild volatile

[6] John Redman Coxe was the author of the letter of presentation quoted in the first article of this series "How Franklin's Electrical Machine came to The Franklin Institute." That article contains an account of his association with the Chemical Society of Philadelphia, the University of Pennsylvania, and The Franklin Institute.

alcali" (ammonium carbonate) produced symptoms with recovery in two days. On the day after the injection, the blood serum of the dogs did not change the color of the indicator.[7]

Philip G. Prioleau (20), in his thesis, presented a series of case reports on the therapeutic use, separately, of nitric acid and of "the Oxygenated Muriatic Acid, or the Dephlogisticated Marine Acid" (chlorine) which he prepared by distilling common muriatic (hydrochloric) acid with "manganese" (manganese dioxide).

From experiments on dogs (22), William Bache[8] ascertained "that fixed air does enter the lungs, and that its sphere of action, if not confined to, is solely directed through, the medium of their cavity." Experiments on flies, spiders, and frogs showed "that the mere exclusion of atmospheric air is not sufficient of itself to produce the violent and sudden effects which are the results of submersion in carbonic acid gas." He also used mice and birds as experimental animals.

Bache concluded "that carbonic acid gas does not produce its effects indirectly, by mechanically excluding atmospheric air from the lungs; but that it acts directly by an inherent power on the animal oeconomy, and particularly through the medium of the lungs." He also stated: "We hold that it acts in some measure upon the nervous system," and "I suppose an inherent property in carbonic acid gas, inducing when combined in too great quantity with the blood, whether arterial or not, such changes in its nature, as to banish from its dominions all oxygenous gas, according to its state of consideration; . . ."

He has vaguely suggested the modern concepts of the action of carbon dioxide on the respiratory center (action on nervous system) and the role of partial pressures of gases, including carbon dioxide, on oxygenation of the blood.

Thomas Semmes (23) studied the action of saccarum Saturni, sugar of lead, lead acetate, on man and dogs. One of his subjects was George Lee, a member of the Chemical Society of Philadelphia and a student of medicine at the University of Pennsylvania 1800–1801. In man, ingestion of 1–5 grains of this salt first increased the rate of the pulse and its force; this was followed by a decrease in both. Gastrointestinal symptoms, especially nausea, developed. The dose of 5 grains produced a highly colored urine. A dog, which had died in

[7] Adam Seybert was a member of the United States House of Representatives from Pennsylvania 1809–1815 and 1817–1819 (21). Books and journals from his library were presented to The Franklin Institute by his son, Henry Seybert, who became a life member of the Institute in 1830. A concise account of Adam Seybert as chemist, mineralogist, pharmacist, and statesman is given by Grady Roney and J. Hampton Hoch (*American Journal of Pharmacy*, Vol. 127, pp. 346–358 (1955)).

[8] The life of William Bache, grandson of Benjamin Franklin and owner of the electrical machine, has been outlined in the first article of this series "How Franklin's Electrical Machine came to The Franklin Institute." The copy of his dissertation in the Armed Forces Medical Library is inscribed: "For Dr. James Woodhouse with the respects of The Author."

delirium and convulsions as the result of administration of lead acetate, on necropsy revealed distended gastric blood vessels, inflammation of the stomach and duodenum, turgid duodenum; the remainder of the intestines, liver, kidneys, and urinary bladder were normal; the gall bladder was full of unusually dark bile. The dedication of the printed thesis reveals that the preceptor of Semmes was Elisba Cullen Dick who graduated in medicine from the University of the State of Pennsylvania in 1782, and was one of the physicians who attended George Washington during his last illness.

John Trent (**24**) was a pioneer in the field of photochemistry. He contended that gaseous oxygen contains light as a component. When carbon, hydrogen, or iron undergo combusion in pure air, light is liberated. In photosynthesis in plants, the evolved oxygen combines with the light. In the alveolar gas exchange, light is liberated from the oxygen and reddens the arterial blood; experiments to support this contention are described.

Joseph Glover (**25**) studied digestion. He ascertained that saliva had no solvent action on roasted veal at body temperature. He had the cooperation of a natural regurgitator or ruminator, that is, a man whose vomiting center in the medulla was under the control of his will. When this man ate a meal of meat (roast beef or boiled mutton), a vegetable (potatoes or cabbage), and bread, and drank water, the mass, regurgitated four hours after ingestion, had an acid taste and imparted a red color to a blue vegetable indicator. The mass, regurgitated two hours after ingestion, was less acid. Glover ate such a meal with corned beef as the meat, and, four hours later, ingested 20 grains ipecacuanha as an emetic; the gastric contents thus obtained were acid. The gastric contents of a cat which had fasted for 48 hours contained no acid. Those of a cat killed five hours after a meal of boiled beef and potatoes and of a dog killed 4½ hours after its last meal of animal food were acid. Some tests were made with rhubarb paper (brown with alkali, yellow with acid). Glover concluded that the acid was not phosphoric, since it was not precipitated by lead acetate solution, and considered it to be a product of fermentation, possibly acetic acid.

Oliver H. Spencer (**26**) depended on a change either in the color of litmus paper or in the blue color of syrup of violets as evidence of the presence of acid. He was unable to detect acid in gastric contents obtained from: (*a*) human subjects by use of tartar emetic 2–5½ hours after ingestion of a meal of bread and butter with or without sausage, (*b*) dogs and cats killed 4–8 hours after a meal of meat or fish, bread, and vegetables. He concluded that, in the healthy stomach, digestion occurs rapidly "without the aliment undergoing any fermentation by which an acid is produced" in either the stomach or duodenum. "When acidity does take place, it is a proof of the unhealthy condition

of the stomach." Digestion was attributed to solution alone by the gastric juice. Possibly the discovery of a large number of lumbricoid (nematode) worms, some 10–12 inches long, in the stomach of one of his experimental animals (a mastiff) prompted the explanation that, by virtue of "the principle of life" or "the vital principle," the stomach does not undergo autodigestion in the living animal, and live animals (the parasitic worms) survive in the alimentary canal.

While the name of John R. Young (27) does not appear in the membership list of the Chemical Society of Philadelphia, his dissertation for the doctorate in medicine at the University of Pennsylvania is a notable contribution to the knowledge of nutrition and digestion. Many of his experiments were made on the common bull frog (*Rana ocellata*). "They have a large membranous stomach, which when distended, occupies the whole anterior part of the abdomen: the oesophagus is very wide, so that their food can be examined at pleasure." The ingested food was removed from the stomach through the oesophagus by forceps, or a teaspoon, or by a thread tied to the food. The food was either live spring frogs (the thread tied to the hind legs), or "pease," wheat, beans, etc., in linen bags. Digestion of the spring frog progressed so that at 7 hours the abdominal muscles were dissolved and the bones of the feet soft; at 13 hours only the legs attached to the thread could be pulled up, and their bones were soft like tender cartilage. A bull frog ate and digested a field mouse; its bones and incisor teeth became soft and flexible. Bread and well bruised beans and peas were completely digested by bull frogs in 2 days, the bags becoming empty. Whole peas, beans, and wheat were not digested. Material (spring frogs, veal, beef, etc.) removed from the bull frog stomach after partial digestion, at least 2 hours after ingestion, was always acid to litmus. When a bull frog had fasted for 2 days, and litmus paper was introduced into its stomach, the paper became red. "Naked" gastric juice, withdrawn from the frog stomach with a teaspoon was "constantly found to be slightly acid." Snakes were also used as experimental animals. They digested frogs and lizards, but digestion was only about one-half as fast as in large frogs.

Young ate meat on an empty stomach, and one-half hour later produced emesis by irritating his fauces. The gastric contents thus obtained were acid. Young had the cooperation of a natural regurgitator whose gastric contents after eating were acid. Young concluded that the acidity of gastric contents is due to phosphoric acid, not acetic acid, and excluded fermentation and putrefaction as digestive processes. He accepted the vital or living principle, asked and answered a question, and described an illustrative experiment. "If animal substances are so readily dissolved by it [the gastric juice] why does not this fluid also dissolve the stomach? . . . The living principle does effectually resist the action of the gastric fluid." When a bull frog swallowed a spring frog, the latter suffocated since the

oesophagus was completely closed and air was excluded from the stomach. This experiment was performed. "Two threads were tied around the forelegs of a live, and common sized spring frog; its whole body, except the head and fore legs was introduced into the stomach of one of the large frogs; the fore legs of the lesser were made to clasp around the lower jaw of the larger frog, and firmly tied in this situation, each of the threads were then tied to the fore legs of the larger frog also: thus situated it was impossible the small frog could be entirely swallowed down, or thrown out of the stomach of the larger one." The animals were kept in a "bason" containing a little water for 1½ days. "The small frog upon being drawn out was perfectly alive, and its whole body covered with gastric juice, and not the least dissolved in any part." When the small frog was killed and introduced into the stomach of the larger frog, its entire surface was completely dissolved in 5 hours. The experiment was repeated using a live small frog with a weakened living principal (a divided great sciatic nerve); at the end of 12 hours, the small frog was drawn out, still alive, and "the paralized extremity was quite sound."

Young mentions nourishment of a patient for many weeks by rectal feeding.

Jarvis Roebuck (**28**) applied qualitative tests to the bile of: ox, calf, dog, sturgeon, man (2 specimens from necropsies). In some or all, he found calcium, chloride, phosphate, "gluten" (protein precipitated by alcohol); iron was absent. He also studied the biliary pigment, and tests for it in blood and urine, by its reactions with mineral acids. Thus a tablespoonful of serum from a human patient with jaundice was treated with 3–4 drops of muriatic (marine, hydrochloric) acid; a green color immediately appeared. Nitric acid produced a green color, sulfuric acid a yellow color. These tests gave no color with normal human serum, or with serum from a patient with pneumonia.

To test for bile in the urine of jaundice, one-half a wine glass of urine was treated with 10 drops of concentrated nitric acid; a deep green color developed which was destroyed immediately on shaking. In this test, hydrochloric acid immediately produced a permanent green color. Normal urine gave no color with nitric acid, a purple color with hydrochloric acid.

When 2 drachms of dog bile were injected into the external jugular vein of a dog, the animal became ill, but gradually recovered. "Thus we have proved the stimulus of bile in the blood vessels, not to be necessarily attended with fatality."

Roebuck apparently isolated cholesterol from human bile as brilliant white plates which separated on the evaporation of the alcohol used to precipitate the "glutinous part" of the bile. This research of Roebuck in 1801 was midway between those on cholesterol by Fourcroy (**29**) in 1789 and Chevreul (**30**) in 1815.

James Hutchinson (31) used a microscope in his examination of the milky serum of a patient, who had been bled as a therapeutic measure, and observed white "spots" about half the size of a pin's head.

Edward Darrell Smith (32) surveyed the literature concerning the entry of "substances" into the circulation.

Benjamin G. Hodge (33) administered green vitriol to dogs by mouth and by rectum, killed them $1\frac{1}{2}$–$3\frac{1}{2}$ hours later, and tested the chyle from the thoracic duct for the presence of iron with ferrocyanide and with tannin with negative results. He also detached the mesenteric glands and cut them into portions, which were immersed in clear water and tested with ferrocyanide and with tannin; soon, respectively, a blue color and a black color developed, showing the presence of iron; the reactions tended to be more marked the longer the elapsed time between administration and death. The colon and rectum of these dogs were described as if fast tending to gangrene, sometimes actually in that state, "being as black as my hat." (Possibly the color was due to the normal formation of ferrous sulfide.)

When powdered gall nut in meat, or its aqueous solution, was fed to a dog, which was killed 2 hours later, the thoracic duct chyle gave a negative reaction for tannin with ferrous sulfate.

A dog was given 60 grains of lead acetate in its food, in doses of 15 grains each, and $\frac{1}{2}$ ounce of the same compound by rectum with "proper precautions" to prevent its expulsion. The animal was killed 2 hours later; chyle of the thoracic duct, the blood, and the mesenteric glands were tested separately for the presence of lead with phosphoric acid and with hydrogen sulfide; the results were negative.

The saliva and the serum of a patient in a high state of salivation were tested for the presence of mercury by its deposition on metallic gold. The results were negative.

Hodge concluded that these experiments gave no reason for admitting the absorption of medicines. Over a century was to pass before the micro methods of the clinical chemist and the toxicologist should be developed, and reveal quantitatively the presence of the absorbed metal!

In a somewhat similar research, John C. Geddy (34) usually obtained positive results. Garlic was used in a cataplasm. When it was applied to the feet of a man for $1\frac{1}{2}$ hours, the characteristic odor was imparted to his urine 2 hours later. When it was applied to the feet of a lactating woman for $2\frac{1}{2}$ hours, the characteristic odor appeared in her milk.

Geddy ingested 5 drops of spirit of turpentine after its dilution; a characteristic violet odor was markedly present in his urine in about an hour. He exposed himself for an hour to an atmosphere containing the vapor (fumes) of turpentine; a slight odor of violets appeared in his urine an hour later. His hands and feet were rubbed for 1 hour with spirit of turpentine, then well washed; they were inflamed for

12 hours; a marked odor of violets appeared in his urine 1 hour after cessation of the rubbing. He kept his feet for ½ hour in a vessel filled with spirit of turpentine; inflammation and pain then compelled their removal from the vessel; a violet odor appeared in his urine in 1 hour and continued to be present for 11 hours.

When Geddy rubbed 2 drams of tartar emetic on his hands for 2½ hours, a slight nausea was produced.

When he applied strong mercurial ointment to the skin on the inner aspect of his thighs for 48 hours, he noted the copper-taste generally produced by the use of mercury.

Evidence was thus obtained of absorption from the digestive tract, through the respiratory system, and through the skin.

William S. Jacobs (35) analyzed five urinary calculi (3 human, 1 sheep, 1 cow) and an intestinal calculus from a horse, chiefly by qualitative methods.

John Syng Dorsey (36) tested gastric juice for its lithontriptic virtue or ability to dissolve urinary calculi or "stone." Thus calculus (weight 7 grains) was placed in a perforated, hollow silver sphere which was swallowed by a man and recovered from his feces 65 hours later; it now weighed 5 grains, was softer, and apparently had partially dissolved.

Experiments *in vitro* were also made with the gastric juice of animals. A fragment of calculus (weight 10 grains) kept for 27 hours in ½ ounce of gastric juice of a dog, lost no weight but became brittle and soft. Repetition of the experiment with a 5-grain fragment yielded similar results. When a fragment was kept in gastric juice of a hog for 17 hours, it lost 1 grain in weight, and was softened; the action was apparent at 3 hours. At a temperature of 96° F. for 20 hours, a fragment weighing 9 grains initially decreased to 7¼ grains, and became softer; its laminae separated.

Dorsey believed that "a gluten or mucus intervenes between the laminae of stones." He stated: "I doubt whether the Gastric liquor dissolves much of the stony matter," but apparently attributed to it an action on this interlaminary compound resulting in separation of the laminae.

He applied therapeutically the gastric juice of fasting hogs, which, he ascertained, contained no acid. Approximately 2–4 ounces of this gastric juice at a temperature of 96° F. were injected through a catheter into the empty urinary bladder of a male patient with stone, in the Pennsylvania Hospital, 24 times, usually daily. The urine, voided 1 or more hours after the injection, usually was turbid, and contained "sand" which probably was derived from the calculus by disintegration.[9]

These research workers had at their disposal few facilities, compared

[9] Dorsey (37) became a member of the faculty of medicine in the University of Pennsylvania, serving as adjunct professor of surgery (1807–1816), professor of materia medica (1816–1818), and professor of anatomy in 1818 (the year of his death).

with those of today. They had the chemical balance and the microscope; a few procedures of physical diagnosis (for example, the rate of the pulse and its force); a few tests, usually qualitative, of analytical and biological chemistry; and a primitive staining technic, used by Hodge. Antisepsis, asepsis, and anesthesia were as yet unknown. Yet their procedures and subjects were quite similar to those of the modern pharmacologist. They used both human subjects and animals.

For human subjects, they used themselves, normal persons, and patients. The examination of regurgitated material has been used during the present century. Brennemann (**38**) studied coagulation of cow's milk in the human stomach by means of a subject who emptied his stomach at will by digital irritation of his fauces. Instead of this procedure, the Rehfuss, or a similar, tube may be used to obtain gastric, or even intestinal contents; Hawk (**39**) has worked extensively in this field.

For animals, these early workers used birds, cats, dogs, flies, frogs, mice, pigeons, rats, snakes, spiders, and worms. The mode of administration of their research material included: oral, rectal, intravenous, subcutaneous, intraperitoneal, urethral, also inhalation, and application to the skin and to the eye.

These men worked thoughtfully and diligently, and carefully recorded their findings. They were truly pioneers in American biochemistry.

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## NUCLEAR ENERGY NEWS

### RESEARCH REACTOR FOR SPAIN

The Government of Spain under its atomic energy agreement with the United States has selected the General Electric Company to supply Spain's first nuclear reactor. Except for the Swiss reactor, which had been built originally as part of the United States government exhibit at the Geneva conference in 1955, this will be the first reactor manufactured in the United States for sale to an European country.

The General Electric Company will install a 3000-kilowatt research reactor in the Moncloa area near Madrid for the Junta de Energía Nuclear (Spanish Nuclear Energy Commission). In addition to manufacturing the reactor and supervising its installation, the G-E Atomic Power Equipment Department, soon to be located in San Jose, Calif., will co-ordinate plans for a reactor building, conduct the start-up operation and provide training for the reactor operators.

This equipment will be used for research in the fields of agriculture and medicine and also will be used to train personnel in the operation of both research and power reactors. Applications will consist principally of studies in nuclear physics and the effects of nuclear radiation on various materials, as well as experiments in bulk shielding.

This installation, known as a "swimming pool" reactor, has a core submerged in a pool of ordinary water which cools the reactor, shields radiation produced by the reactor and slows neutrons to a desired energy range.

The reactor will be rated at 3000 kilowatts of heat. The fuel will be enriched to 20 per cent in U-235, which can be made available under the agreement between Spain and the United States.

Experimental facilities will include six neutron beam ports which transmit radiation from the reactor core into experimental areas; a 4 by 4-ft. thermal column which transmits thermal neutrons, and two pneumatic tubes which transport containers of sample materials past the reactor core either rapidly or slowly, depending on test requirements.

### RESEARCH REACTOR FOR JAPAN

The first nuclear reactor for the Far East will be built by Atomics International, a Division of North American Aviation, Inc., for the Atomic Energy Research Institute of Japan. A contract between the two organizations calls for completion within a year of a 50-kilowatt nuclear research reactor to be located near Tokyo. It will cost about $250,000.

The Atomic Energy Research Institute, a non-profit foundation sponsored by the Japanese government and industry, will use the reactor for studies in the field of botany, biology, agriculture, materials research, production of radioisotopes, and student training, in addition to general research in the nuclear field.

The reactor will be similar to the industrial research reactor designed and built by Atomics International for the Armour Research Foundation in Chicago. It will be a "solution type," fueled with an uranium salt dissolved in water. About 2½ lb. of nuclear fuel will be required. Arrangements for fuel will be made between the Japanese and the U. S. Governments.

### ORGANIC MODERATED REACTOR EXPERIMENT

A new type of experimental nuclear reactor to help find out how to lower costs of electricity from nuclear fuel will be designed and built by Atomics International, a division of North American Aviation, for the Atomic Energy Commission.

The reactor, to be built at the AEC's National Reactor Testing Station in Idaho, is scheduled for completion late this year. This small experimental unit will be known as the Organic Moderated Reactor Experiment (OMRE). The estimated cost is $1.8 million, of which Atomics International will bear approximately $750,000.

About 16,000 kilowatts of power in the form of heat will be produced by the reactor. Present plans do not call for the conversion of this heat into electricity, as the experimental program will be concerned only with the technologies associated with the reactor itself.

An organic material, a hydrocarbon such as diphenyl, will have the dual role of "moderator-coolant" in the reactor system. As a moderator, the material will "slow down" neutrons produced in the fission process, helping to sustain the chain reaction. As a coolant, the organic material, which will be in a liquid state while the reactor is in operation, will circulate through the reactor core where heat from the fission process will be absorbed and carried outside to heat exchangers.

The core for the reactor will consist of plate-type fuel elements containing uranium highly enriched in U-235. Use of diphenyl as a coolant offers advantages which stem from the inherent properties of the material: (1) it has a high hydrogen content which makes it an an excellent moderator; (2) it boils at relatively high temperatures compared with water, so there is no need to maintain the compound under high pressures; (3) it causes negligible corrosion with standard materials of construction; (4) it does not react readily with uranium; (5) it becomes only slightly radioactive upon exposure to nuclear radiation.

Problems to be solved are concerned chiefly with the effect of heat

and radiation on the organic coolant. They tend to cause the liquid to deteriorate. The primary purpose of the Organic Reactor Experiment is to determine the irradiation and thermal stability of diphenyl and other organic coolants under conditions found in a prototype power reactor.

Potential organic coolants have been investigated for several years in laboratory scale experiments. These investigations, continued as a supporting phase of the OMRE project, call for the design, construction and operation of an "in-pile loop" in the Materials Testing Reactor at the Testing Station. In this phase diphenyl will be circulated through the test reactor to obtain preliminary information on the behavior of the material under conditions similar to those planned for the OMRE.

Atomics International has been named as "Design Agent" for a nuclear power reactor of the OMRE type proposed by the city of Piqua, Ohio, to the AEC in connection with the commission's Power Demonstration Reactor Program for small capacity nuclear power plants. The reactor for Piqua would have an electrical capacity of 12,500 kilowatts and would be completed by 1960. The Piqua proposal is contingent upon the success of the OMRE.

### EXPERIMENTAL BREEDER REACTOR DAMAGED DURING EXPERIMENT

The core of the Experimental Breeder Reactor No. 1 at the National Reactor Testing Station in Idaho was damaged in an experiment to determine the behavior of the reactor during sudden power increases. Such experiments are aimed at better understanding of the associated problems of reactor control.

During a planned power surge in the course of the final experiment of a series on November 29, 1955, a verbal instruction to shut the reactor off instantly was misunderstood and as a result enough heat was produced to damage the core. Some radioactivity was released within the building which was promptly evacuated. No significant radiation exposure or damage other than to the core occurred as a result of the experiment.

The announcement of the accident was made by the Chicago Operations Office of the Atomic Energy Commission on April 5, 1956. At that time it was stated that the full extent of the damage to the core could not be determined until it had been removed and examined.

### PROGRESS REPORT OF INSURANCE STUDY GROUP

A study group of insurance executives was established by the AEC in March 1955 to review insurance problems created by expanded industrial participation in atomic energy. Its first progress report was issued in July 1955 (see this JOURNAL, Vol. 260, p. 318). A second progress report was issued in March 1956.

Substantial progress has been made in dealing with the problem of the abnormally large amounts of third party liability insurance which are being sought to cover an atomic installation in case of a catastrophe. The stock casualty companies and the mutual companies are in process of developing separate insurance pools having a total capacity of $65 million, all of which would be available at any one installation.

A separate pool aggregating $50 million is being orgainized by the stock fire insurance companies exclusively to cover physical damage to the property of the insured. Damage resulting from radiation or radioactive contamination to buildings and equipment would be included.

The task of organizing these large insurance pools is not yet completed. Also the question of rates has not been settled. The insurance study group contemplates further study of the problems and expects to submit further reports to the Commission.

### COMMISSION ANNOUNCES GEM IRRADIATION POLICY

The U. S. Atomic Energy Commission has announced that requests for irradiation of gems in Commission facilities will be treated in the same manner as requests for irradiation of other materials. The Commission's decision removes a suspension of gem irradiations which has been in effect since 1953.

It has been known for more than 50 years that color changes may be produced in gems by irradiation. Radium, and more recently particle accelerators, cobalt-60 and nuclear reactors have been used for this purpose. Radiations from a particle accelerator may produce blue or blue-green colors in diamonds. Irradiation in a nuclear reactor may produce a green color, which may be turned to brown under certain conditions of heating.

In April 1953 the Commission temporarily suspended the issuance of authorizations for irradiation of diamonds and other gems in Commission facilities pending study of the policy involved in such irradiations. As a result of the study, it was decided that requests for gem irradiations should be handled in the same manner as other requests for service irradiations. Commission policy is to authorize irradiations when reactor space is available. A fee covering the cost of providing the irradiation service is charged.

The Commission noted that "Trade Practice Rules for the Diamond Industry" were published by the Federal Trade Commission on February 10, 1956. The rules, which went into effect on March 10, 1956, provide in part:

DECEPTION AS TO COLOR. . .

It is an unfair trade practice to advertise, offer for sale, or sell any diamond which has been artifically colored or tinted by coating, irradiating, or heating or by use of nuclear bombardment, or by any other means, without disclosure of such fact to purchasers or prospective purchasers, or without disclosure that such artificial coloring or tinting is not permanent if such is the fact.

Diamonds irradiated in a nuclear reactor become radioactive temporarily, but the radioactivity decays to an insignificant level within a few days.

### TWO PARTICLE ACCELERATOR PROJECTS FOR AEC

The U. S. Atomic Energy Commission has approved the construction of two high-energy particle accelerators, one of which will be a joint Harvard University-Massachusetts Institute of Technology project located at Harvard, and the other a joint Princeton University-University of Pennsylvania project located at Princeton.

The Harvard-MIT accelerator will be a 6-billion electron volt machine, with an estimated cost to the Government of $6,500,000. The Princeton-Pennsylvania machine will have an energy of three billion electron volts, and will be built at an estimated cost to the Government of $5,800,000.

The two proposals were accepted after the Commission had canvassed all U. S. universities which have substantial interest in high-energy physics to determine their interest in and capability of designing and constructing a high-energy accelerator.

The machines will be used for basic research in high-energy physics—a field of investigation fundamental to the understanding of nuclear structure and forces. It is proposed that the machines be made available for research by scientists from other institutions, in addition to the four participating universities.

The Harvard-MIT machine will be a circular alternating gradient electron synchrotron, with a 118-ft. radius. It will be constructed in about three and one-half years on a site adjacent to the Harvard Cyclotron Laboratory.

The Princeton-Pennsylvania accelerator will be a uniform gradient proton synchrotron, to be completed in about 4 years at the Forrestal Research Center. It will resemble the Cosmotron at Brookhaven National Laboratory, but is expected to have a higher beam intensity.

Each facility will include 21,000 sq. ft. of laboratory, office and shop space, as well as buildings to house the accelerators, power supplies and experimental areas. After their construction is complete the accelerators will be operated by the institutions under contracts with the Commission.

## NOTES FROM THE NATIONAL BUREAU OF STANDARDS

### AN OCEAN-BASED AUTOMATIC WEATHER STATION

A prototype marine weather station that automatically reports local weather data by radio has been developed by the National Bureau of Standards. The unit is incorporated in a buoy that can be anchored in remote locations and left unattended for periods up to six months. At regular intervals throughout the day, the station broadcasts in code the air temperature, water temperature, barometric pressure, and wind speed and direction. Preliminary tests in Chesapeake Bay show that the station has a radio range in excess of 800 miles. The equipment was developed by P. D. Lowell, W. Hakkarinen, and L. M. Allison of the Bureau's electronic instrumentation laboratory for the Navy Bureau of Aeronautics.

At the present time the gathering of comprehensive weather data from many ocean areas outside of regular shipping lanes is haphazard and limited. Both military and civilian authorities would be better able to predict weather conditions if they received continuous weather reports from a much wider area. If a series of stations similar to the Bureau's prototype station were placed over wide areas of the Pacific Ocean, for example, they could give operations officers and meteorologists frequent reports making possible a complete weather picture for the entire ocean. If moored in certain areas of the Caribbean, these stations might also give warning of hurricanes as they begin to form.

The automatic station translates information from each of five weather sensing elements into three-letter groups in continental code and transmits the coded signals on a pulse-modulated carrier frequency at about 6 megacycles. These signals can be received on standard communications receivers and compared with a decoding table which gives numerical values for each of the meteorological variables measured. A single transmission takes three minutes. During this interval six items of information are broadcast. The first transmission is a three-letter signal identifying the station. Coded transmissions follow containing information on (1) air temperature between $-25°$ and $-110°$ F., (2) water temperature between 15° and 90° F., (3) barometric pressure between 950 and 1050 millibars, (4) wind speed from 0 to 68 knots, and (5) wind direction oriented from magnetic north.

The vessel which carries the weather-sensing and radio transmitting equipment was designed by the David Taylor Model Basin and is 20 ft. long and 10 ft. wide. It is constructed of aluminum and other non-magnetic alloys to avoid undesirable effects on the compass. The

vessel can be anchored in waters as deep as 3600 ft. Two masts and four water-tight wells extending below the boat deck hold all the electronic and meteorological equipment assembled in compact, shock-mounted units. Each unit may be replaced independently of the others.

The weather sensing elements convert variations of water surface conditions into variations of resistance for measurement by a motor-driven self-balancing bridge circuit. The air- and water-temperature sensing devices are simple thermistors. A precision barometer measures air pressure. This barometer is so modified that a slave needle rides above a resistance strip and is clamped to the strip at the time of measurement. An especially rugged three-cup anemometer drives a small magnetic generator whose output is applied to the grid of a vacuum tube. Plate resistance of the tube is measured in the bridge. The wind vane is connected to a selsyn transmitter and receiver circuit activating a servo system. The servo positions a magnetic compass synchronously with the wind vane. Mounted on gimbals, the compass has a slave needle and clamping system that gives resistance values corresponding to the wind direction relative to magnetic north.

Prelimary power comes from 180 4FH dry cells connected in series-parallel to give 13.5 volts at 15 amperes. A rotary converter changes the low-voltage dc to 120 volts at 60 cycles to operate the power supply for the electronic components. In future models of the boat stations, a gasoline-powered generator and storage battery will replace the dry battery supply.

At some predetermined time after a suitable warmup period, a master timer closes the contacts that feed power to all circuits. A chronometer watch, rewound by motor at the time of station activity to ensure accuracy over extended periods of time, furnishes reliable master control. When the power is applied, a program timer, consisting of a number of circular switches driven by a constant speed motor, inserts a precision resistance into the self-balancing bridge. As the first radio signal to be transmitted is the station identifying signal, this precision resistor, instead of one of the weather variable resistances, is the first contacted in the program timer. The resistance of a helical potentiometer at the bridge balance point matches this resistance. On the same shaft with the potentiometer is a rotary code selector switch that selects letters on a code generator; these letters then correspond to the value of the resistor inserted into the bridge. The code generator, a drum made up of eight metal rings insulated from each other, has the code characters machined in relief on the inner circumference of the rings. A comb-type brush contactor sweeps inside the drum, contacting the raised segments. The raised code characters designated by the selector switch, when in contact with the comb, close a keying relay circuit. Then, over a 20-second interval, the

transmitter is keyed in code with a three-letter group. Sending speed can be controlled by the comb speed, and a rate of five to seven signal repetitions during the 20-second interval permits even inexperienced operators sufficient time to copy the signal.

During the interval when the station is identifying itself, a resistance determined by the first of the five weather variables is connected to the bridge circuit. At the end of the identification interval, a 10-second delay ensues while bridge balance and code selection occur. Then the first of the weather data is broadcast. While this signal is being transmitted, the next weather variable is selected and then transmitted at the end of the first weather signal. The remaining variables are transmitted in like manner. Altogether, the three-minute transmission period contains six transmission intervals of 20 seconds duration, each preceded by 10-second balancing intervals. At the conclusion of the transmission period, the master timer contacts are broken to remove power from the equipment until time for the next period of station activity.

### ABRASION TESTING MACHINE FOR PORCELAIN ENAMELS

A simple, rapid device for determining the abrasion resistance of porcelain enamels has been developed at the National Bureau of Standards. The instrument provides a reliable means for testing enamels having different types of finishes, including "orange peel" and wavy surfaces. While the abrasion tester was designed primarily for porcelain enamels, it can be used for determining the wear resistance of such other materials as highway paints, plastic and fibrous materials, and organic finishes. The instrument and test method were developed for the Porcelain Enamel Institute by G. Warren and J. H. Giles, PEI Research Associates at the Bureau.

Abrasion resistance is one of the most important factors in the service performance of protective coatings. Floor coverings are subjected to scuffing, and enameled sinks and cooking utensils are frequently scoured with cleansing powders containing fine abrasives. Since all enamels are not equally resistant to abrasion, techniques for predicting the service behavior on the basis of laboratory measurements are of considerable value to porcelain-enamel manufacturers. The Bureau, in cooperation with the Porcelain Enamel Institute, has been working for a number of years on the development of suitable methods and instruments for testing surface coatings. The most recent result of this work is the PEI abrasion tester.

The instrument consists essentially of a motor-driven table gyrating in a horizontal plane at 300 rpm. The table moves parallel to itself, and describes a circle $\frac{7}{8}$ in. in diameter. The table is driven by a $\frac{1}{4}$-hp synchronous motor, and testing time is accurately controlled by an

electric timer. Nine specimens, 4½ in. sq., can be fastened to the table for simultaneous testing.

A specimen is placed in one of the nine available positions on the table and secured with a rubber-coated aluminum retaining ring. An abrasive charge consisting of 3 g of abrasive grit, 175 g of stainless steel balls (5/32 in. diam.), and 20 ml of water is poured into an accessory hole in the top of the retaining ring. The apparatus is then set to oscillate for the required time. The effectiveness of the abrasive is increased by the motion of the steel balls on the moving specimens.

Two test methods have been devised; one for determining surface abrasion resistance and the other for subsurface abrasion resistance. The surface abrasion test is used when appearance is the main consideration, but the subsurface test method is followed when protection of the underlying metal is the more important. In the first method, Pennsylvania glass sand, between 70 and 100 mesh, is used in the abrasive charge, and the test is run for five minutes. The specular gloss is measured before and after the test, and the percentage retained gloss at 45° is the surface abrasion index.

For determining subsurface abrasion, a coarse fused alumina grain is used for the abrasive grit, and the test is operated for 45 minutes. The slope of the portion of the abrasion time-weight loss curve between the 15- and 45-minute points is taken as the abrasion index. The specimen is weighed at the end of each of three 15-minute abrasion periods; a fresh charge is inserted at the beginning of each period.

Tests of several porcelain enamels in the abrasion tester at four cooperating laboratories have led to the conclusion that the two test methods give satisfactory reproducibility. Results of the experiments show that the indices of abrasion resistance assigned to the various enamels are in general agreement with service experience.

# THE FRANKLIN INSTITUTE

## MINUTES OF THE STATED MEETING
## MAY 16, 1956

The Stated Monthly Meeting of The Franklin Institute was held May 16, 1956, in the Lecture Hall. Mr. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. with approximately 160 members and guests in attendance.

There being no corrections, changes or additions to the minutes of the April Stated Meeting as printed in the May 1956 JOURNAL, they were approved as submitted.

The Annual Report of the Board of Managers for 1955 which will be printed in the July 1956 issue of the JOURNAL was summarized by Mr. Rolph.

The President then presented the speaker of the evening, Dr. Thomas H. Johnson, Director of the Division of Research of the United States Atomic Energy Commission, who is no stranger to The Franklin Institute as he was a former Assistant Director of our Bartol Research Foundation. Dr. Johnson's talk on "High Energy Accelerators in the Atomic Energy Program" was most interesting.

The meeting adjourned at 10:00 P.M. with a rising vote of thanks to Dr. Johnson.

CECIL M. WATERBURY
*Assistant Secretary*

# JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

COULSON, THOMAS: Philadelphia and the Development of the Motion Picture

MITCHELL, E. H.: Analysis of Magnetic Circuits with Given D-C. Excitation

BATTEN, H. W., H. L. SMITH AND H. C. EARLY: Plasma Fluctuations in Crossed Electric and Magnetic Fields

PIPES, LOUIS A.: Matrix Theory of Skin Effect in Laminations

PENFIELD, ROBERT AND HENRY ZATZKIS: The Relativistic Linear Harmonic Oscillator

LEE, LAWRENCE H. N.: Non-Uniform Torsion of Tapered I-Beams

SALZER, HERBERT E.: Osculatory Extrapolation and a New Method for the Numerical Integration of Differential Equations

ATKINSON, CYRIL P. AND L. O. HEFLINGER: Subharmonic and Superharmonic Oscillations of a Bilinear Vibrating System

MOORE, E. F. AND CLAUDE E. SHANNON: Reliable Circuits Using Less Reliable Relays

## MEMBERSHIP

### ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS

### MAY 16, 1956

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Robert Trotta
William P. Wood
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June E. Norris
Perry E. Wightman

#### NECROLOGY

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John B. Bement '46
John S. Clement '42
E. J. Elliott '48
Joseph B. Ennis '44
Harry Garrett '52
Samuel F. Gordon '44
T. Truxton Hare '36
George M. Illman '44
Charles Klause '43
Clinton Mayer '36
George V. Shaw '55
L. O. Veith '52

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## LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor, 227 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays. Thursdays and Fridays; 2 P.M. until 10 P.M. on Wednesdays; and 9 until noon on Saturdays.

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## TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

## NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

### BRIDGES

The new activity on bridges in the Philadelphia area serves to remind us that gigantic strides have been taken in bridge building since the Colonists had to construct the first footbridges in order to move about the country. These were mere logs thrown across a stream. When the width of the stream exceeded the length of the available timber the bridge builder had to devise something more complicated. The first notable effort at bridging a wide river did not take place until the middle of the 18th century, when Major Sewall bridged the York River in Maine. This bridge consisted of thirteen sections, each supported by four pilings. These pilings were saplings of varying lengths, floated down stream into position, guyed, and driven into the river bed by hand operated mauls and an ingenious pile driver, a heavy oak beam fastened on shore. Pulleys raised the free end of the beam, and when it was released it fell with sufficient force to drive the pile into the mud. The center section was arranged as a drawbridge to permit the passage of vessels.

While most of the first bridges were built of wood without much regard for permanence, the time arrived when thought had to be given to their endurance. Benjamin Latrobe built the famous masonry arch at Carrolton Viaduct in Maryland in 1829. It is still in use, carrying loads a hundredfold greater than was originally anticipated for it. With the development of the railroads came the need for strong and numerous bridges. Plate girder construction, an assembly of rivetted plates and angle irons to support the rails, was devised. The truss form of construction was introduced, and by the middle of the 19th century, an all-iron truss had been produced.

These bridges all required supports when the river to be spanned was wide, but there came a time when rivers were too wide and too deep to be spanned by any combination of trusses and girders. To surmount this difficulty, John Roebling built the first suspension bridge over the Niagara River in 1855, and thereby set an example that has been followed in a great many cases, expecially when piers in midstream might interfere with river traffic.

A curious legal situation was created by those bridges that required supports to be erected on piers laid in midstream. The Rock Island Railroad built a bridge across the Mississippi River in 1855. A steamboat was wrecked upon one of the piers and the owners sued the railroad

for damages. Counsel for the defense was Abraham Lincoln who, by winning a favorable verdict for his clients, succeeded in establishing the legal right for a railroad company to build bridges over navigable streams.

The suspension bridge is the most graceful of all spans, but few people who have reason to use it can form an idea of its enormous strength. Visitors to the Museum are able to form a clear conception of the detailed construction of the massive cables that provide the suspension. A short section of the cable used on the Benjamin Franklin Bridge over the Delaware River has been restored to exhibition.

Each of the two cables is 30 inches in diameter, and is composed of 18,360 separate wires. The cables were built up by a travelling "spider" which spun them from end to end. An examination of the ends of the section of the cable will assist the visitor to understand how it is that 22,100 miles of wire, weighing 6100 tons, were employed in the construction of the two cables. The individual wires can be seen clearly.

Local residents, long familiar with the Benjamin Franklin Bridge, may be interested in the Walt Whitman Bridge now under construction lower down the river. In order that visitors may have an opportunity to examine in detail the construction of this new bridge, arrangements have been made for display in the near future of an 8 ft. model. This will be exhibited in the Bethlehem Steel Company's exhibit room, on the First Floor.

## NOTES FROM THE BARTOL RESEARCH FOUNDATION

### ELECTROMAGNETIC ACCELERATION OF PARTICLES TO COSMIC RAY ENERGIES*

BY

W. F. G. SWANN

It has been demonstrated that if a particle is accelerated in an electromagnetic field between two points designated by subscripts (1) and (2), the particle will gain energy in passing from (1) to (2) provided that the quantity $J$ defined by

$$J = \int \frac{\partial}{\partial S}(U_{S2} - U_{S1})^2 - 2\frac{\partial U_S}{\partial t}\int \frac{\partial U_S}{\partial S}\,dt$$

is positive, where $dS$ is an element of path, $U_{S1}$ and $U_{S2}$ are the initial and final values of the vector potential along the path, and $t$ is the time. Moreover, if the particle at rest at the point (1), its energy $W_2$ at the point (2) is such that

$$W_2 > e|(U_{S2} - U_{S1})|$$

where $e$ is the charge on the particle.

The foregoing theorem has been applied to the case where the motivating agency responsible for the electromagnetic field is a toroid with currents circulating in such fashion as they would circulate if the anchor ring of the toroid were wound with a wire in which a current decayed with time. The particular case studied is that where a particle moves along the axis of symmetry, and dimensions are chosen of astronomical size such as to make them apply to such phenomena as are observed in the Crab Nebula.

The magnitudes chosen are as follows:

$a \equiv$ Radius of cross section of the toroidal winding = 1 light year

$r_0 \equiv$ Mean radius of toroid = 2000 light years

$H_0 \equiv$ Initial field in the toroid = $10^{-3}$ gauss

$v/\alpha \equiv$ Time for the current to decay to $1/e$ of its initial value = 1000 years.

With the above assumptions, a particle of electronic charge, starting from the center of the toroid and travelling along the axis of symmetry would acquire an energy in excess of $3 \times 10^{14}$ electron volts.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

## THE RADIATIONS OF $Sn^{125}$ AND $Br^{82}$ *

BY

V. S. DUBEY,[1] C. E. MANDEVILLE AND M. A. ROTHMAN

Employing coincident scintillation counters of NaI(Tl) and anthracene, beta-gamma and gamma-gamma coincidence studies have been carried out to determine the decay schemes of $Sn^{125}$ and $Br^{82}$. Gamma rays have been detected with quantum energies of 1960, 1410, 1070, 900, 810, 470, 340, and 230 kev in the disintegration of $Sn^{125}$, and with energies 250, 350, 560, 610, 690, 770, 820, 1030, 1290, 1450, 1800, and 2050 kev in the decay of $Br^{82}$. The energy levels located by the combined energy and coincidence data are,

for $Sb^{125}$: 1070, 1410, 1880, 1970, and 2110 kev;

for $Kr^{82}$: 770, 1450, 1800, 2060, and 2620 kev.

These results can be interpreted on the basis of the single particle model to determine likely spin values for the nuclear states.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] On leave of absence from Agra College, Agra, India.

## THE RADIOACTIVITY OF VICTORIAN GLASS

BY

C. E. MANDEVILLE

It is well known that during the last century, uranium was often employed to provide coloration for glass objects. In particular, sodium diuranate was added to both flint and soda lime glass to produce a yellow or yellow-green hue (vaseline glass). Measurements with a scintillation counter show that uranium compounds were introduced into "apple green" and "green" glasses as well. In a geometry providing a relatively poor solid angle, the following gamma-ray counting rates have been observed.

| Object | Weight, grams | Counts/min |
|---|---|---|
| Vaseline Glass Vase | 200 | 2,500 |
| Apple Green Candle Holder | 230 | 2,100 |
| Green Candle Holder | 210 | 800 |

Samples of these three types of colored glass are also noted to fluoresce vigorously under black light, emitting the characteristic green radiation of the $UO_2^{++}$ coordination group which is in solution in the glass. Whether or not these properties will be useful in distinguishing in the future between antique items and recently made reproductions will be determined by the legal circumstances throughout the world which may surround the continued use of uranium in glass products.

## RADIATIONS FROM $Eu^{155}$ AND $Sm^{153}$*†

BY

V. S. DUBEY,[1] C. E. MANDEVILLE AND M. A. ROTHMAN

Using coincident scintillation spectrometers employing single channel analysis as well as a slow-fast circuit incorporating a 20-channel analyzer, the radiations of $Eu^{155}$ and $Sm^{153}$ have been investigated. $Eu^{155}$ is found to decay with emission of two beta spectra having end points of 240 kev (21 per cent) and 150 kev (79 per cent). A gamma ray was detected at 102 kev. An 84 kev–18 kev cascade is also present. The harder beta spectrum is non-coincident with gamma radiation. All beta-gamma coincidences observable at beta-ray energies greater than 150 kev are attributed to the presence of $Eu^{152,154}$. The beta spectra of $Sm^{153}$ are found to have end point energies of 825, 720, 645, and 130 kev and relative intensities of 27, 32, 40, and ~0.06. The gamma rays of $Sm^{153}$ have quantum energies of 70, 100, 170, 530, and 600 kev. The relative intensities of the transitions associated with these gamma rays are, when corrections are introduced to take into account internal conversion, 0.68, 1.0, $4.5 \times 10^{-4}$, $6.5 \times 10^{-4}$, and $1.5 \times 10^{-4}$.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Presented at the Washington Meeting of The American Physical Society, April 26–28, 1956.

[1] On leave of absence from Agra College, Agra U.P., India.

## NUCLEAR RESONANCE FLUORESCENCE IN $O^{16}$ *†

BY

C. P. SWANN AND F. R. METZGER

Using the Bartol-ONR Van de Graaff generator and the reaction[1] $F^{19}(p,\alpha)O^{16}$ as the gamma-ray source, nuclear resonance fluorescence in $O^{16}$ has been observed. A thick target of $CaF_2$ was bombarded with $2\mu a$ of 3 Mev protons to give a source strength of about $10^9$ gamma rays per second. A ring geometry similar to the one employed in previous resonance fluorescence experiments[1] was used. Water and benzene scatterers were compared and the difference in the counting rates was attributed to resonance fluorescence in oxygen. Great care was taken to eliminate all neutrons since their presence tended to conceal the effect. Of the first four levels in $O^{16}$ only the 6.91 Mev and 7.12 Mev states can be responsible for the resonance effect. The angular distributuon of the resonance radiation shows indeed that both of these

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Presented at the Washington Meeting of The American Physical Society, April 26–28, 1956.

[1] See for example, FRANZ R. METZGER, *Phys. Rev.*, Vol. 101, p. 286 (1956).

levels participate. The reduction of the resonance effect by means of a water absorber placed between the gamma-ray source and the scatterer indicates that the lifetimes of these two levels are the same to within a factor of three. Preliminary measurements give lifetimes between $10^{-14}$ and $10^{-15}$ seconds.

## RADIATIONS FROM $Au^{195}$ *†

BY

V. R. POTNIS[1]

The radiations from $Au^{195}$ have been examined previously in magnetic spectrometers and coincident Geiger Counter arrangements. Two gamma rays with energies about 31 and 99 kev were found to be in cascade in all these studies. The data concerning the presence of the 130 kev cross-over transition of the 31–99 kev cascade have been inconclusive. In order to find some definite evidence of the presence of the 130 kev gamma ray, the radiations from $Au^{195}$ were examined with the scintillation spectrometer of NaI(Tl). The presence of 31, 99, and 130 kev gamma rays is seen in the pulse height distribution of the gamma rays. Absorption experiments on each gamma ray were carried out. It has been shown that the 130 kev gamma ray is not due to the simultaneous detection of the two lower energy gamma rays in cascade.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Presented at the Washington Meeting of The American Physical Society, April 26–28, 1956.

[1] Permanent address, Gwalior (M.B.) India.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, M.D., FOUNDER
WILLIAM G. BATT, D.Sc., DIRECTOR

# SCREENING OF COMPOUNDS FOR ANTI-TUMOR ACTIVITY. EFFECTS OF SOME SUBSTITUTED PYRIDINES ON THE GROWTH OF WALKER CARCINOSARCOMA 256 IN TISSUE CULTURE

BY

FRANCIS E. REINHART, J. H. GRAY, AND WILLIAM G. BATT

In connection with a general program for detection of anti-tumor activity concerned mainly with variously substituted pyridines, it was considered of interest to carry out a preliminary screening of some of these materials with respect to possible inhibitory effects on the growth of the Walker 256 rat tumor in tissue culture.

The compounds used were among those which had been prepared at previous times in this Laboratory.

Four tissue fragments (1–2 cu. mm.) which were obtained from 8–10 day tumors maintained in Charles River rats were introduced into a Carrel flask (D 3.5) containing chicken plasma (0.35 ml.) and nutrient mixture (0.65 ml.). After a firm clot had formed, 0.9 ml. nutrient mixture was added. The nutrient mixture consisted of chick embryo extract EE-50[1] (3.75 ml.), horse serum[1] (8.75 ml.), Earle's salt solution (6.25 ml.), penicillin G (1.87 ml. of 1000 U/ml. aqueous solution), and streptomycin sulfate (0.94 ml. of 100 μg/ml. aqueous solution).

Flasks were set up in triplicate for observations on the effect of each concentration of each chemical, which was introduced as 0.02 ml. of a 95% ethanol solution (or suspension) so as to yield the final concentration noted in Table I. Similar flasks in triplicate but containing 0.02 ml. ethanol served for observations on the growth of tumor controls. Separate experiments indicated that the ethanol at this concentration had no observable effect on tumor growth.

All flasks were introduced into a large desiccator, flushed with 5% carbon dioxide–95% air mixture, and incubated at 37° C. Low-power microscopic observation of tissue growth was made after 72 hours.

The results of these experiments are recorded in Table I. Activity at concentration of 50 μg. per ml. is seen to be lacking in the derivatives of 3-pyridinesulfonamide (compounds I–IV). Only moderate inhibition is evidenced by the sulfones (V–VII) and by compounds X and XI. The growth-inhibitory property of the most active compound in this group, compound XII, has been consistently observed in repeated experiments. It is to be noted that both the dithio (XIII) and sulfonyl (XIV) analogs of 2,2′-thiobis[5-nitropyridine] (XII) were observed to

[1] Purchased from Microbiological Associates, Inc.

TABLE I.—*Anti-Tumor Activity of Substituted Pyridines.*

| No. | Compound | Melting Point ° C. | Method of Synthesis | Conc. μg./ml. | Inhibition |
|---|---|---|---|---|---|
| I | 3-Pyridinesulfonanilide | 145 | (1) | 50 | none |
| II | N-(3-Pyridyl)-3-pyridine-sulfonamide | 182 | (1) | 50 | none |
| III | Ethyl 4-(3-pyridinesulfonamido)-benzoate | 156 | (1) | 50 | none |
| IV | 4-(3-Pyridinesulfonamido)-benzoic acid | 241 | (1) | 50 | none |
| V | 5-Nitro-2-(phenylsulfonyl)-pyridine | 152–3 | (2) | 50 | complete |
| | | | | 20 | complete |
| | | | | 10 | none |
| VI | 5-Nitro-2-(*m*-nitrophenylsulfonyl)-pyridine | 169 | (2) | 50 | complete |
| | | | | 20 | none |
| | | | | 10 | none |
| VII | 5-Nitro-2,3′-sulfonyldipyridine | 153 | * | 50 | complete |
| | | | | 20 | complete |
| | | | | 10 | slight |
| VIII | 5-Nitro-2-pyridinethiol | 179–81 | (3) | 50 | none |
| IX | S-(5-Nitro-2-pyridyl)thiuronium Chloride | 187–90 | (4) | 50 | none |
| X | 6-Mercaptonicotinonitrile | 253–4 | (5) | 50 | complete |
| | | | | 20 | none |
| | | | | 10 | none |
| XI | S-(5-Cyano-2-pyridyl)thiuronium Chloride | 188–90 | (5) | 50 | complete |
| | | | | 20 | slight |
| | | | | 10 | none |
| XII | 2,2′-Thiobis[5-nitropyridine] | 136 | (4) | 50 | complete |
| | | | | 20 | complete |
| | | | | 10 | complete |
| | | | | 5 | complete |
| | | | | 2.5 | none |
| XIII | 2,2′-Dithiobis[5-nitropyridine] | 150 | (6) | 20 | none |
| XIV | 2,2′-Sulfonylbis[5-nitropyridine] | 209–10 | ** | 50 | none |

* Unpublished data.
** Prepared by oxidation of XII with hydrogen peroxide. Cf. A. R. SURREY AND H. G. LINDWALL, *J. Am. Chem. Soc.*, **62**, 173 (1940).

be inactive at the levels tested. Further studies on the latter substance with respect to animal toxicity and possible anti-tumor activity in tumor-bearing animals are in progress.


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## NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

### 12-CHANNEL SEQUENTIAL EVENT RECORDER

BY

C. W. HARGENS

The drum camera[1] has been used frequently to record a number of phenomena simultaneously, showing their time relationship. A shortcoming of the drum camera resides in the fact that all of the records are made upon the same time base. This cannot be avoided since all records are "written" on a single cylindrical surface, turning at a constant angular rate.

Another shortcoming of the drum camera concerns its time resolution in cases where the transient phenomena are individually of short duration, but widely spaced. Since the entire series of events must be accommodated on the peripheral trace, the regions of interest may occupy only a small space. Most of the trace of each channel, consisting of an uninteresting straight line, is wasted.

The type of phenomenon recorded on a drum camera is aperiodic and usually transient in character. One would like to select that part of the time base during which the record is of interest and exclude the rest. The desire to do this led to the development of an electronic recorder (Fig. 1) which permits the important portion of the trace to be selected and examined critically.

A cathode-ray tube is provided for each channel of the system. These are grouped together so that they may be photographed. Then by timing the events we are able to view each signal as it occurs and yet retain the true time relationship between all channels as a part of the photographic record. This is done by auxiliary coding.

The timing of the system is accomplished as follows: An initiator pulse is produced by the instrument for the purpose of triggering the phenomenon or device which is under study. At various times thereafter signals arrive at the channel inputs to be recorded (Fig. 2). Since each channel has its own cathode-ray tube display with individual sweep circuit, the various arrival times may be accommodated.

The individual cathode-ray tube sweeps are related by a common delay system keyed to the initiator pulse just mentioned. By providing a finite number of delay possibilities which may be applied to any channel, it is possible to code the record with the channel delay. This is

[1] J. J. Barton, H. G. Clarke and W. W. Shugarts, *Industrial Photography*, Jan.–Feb., 1955.

done by turning on a number of tiny lights arranged around the periphery of each tube, corresponding to the delay selected. The start of each trace is then known relative to the zero time reference represented by the initiator pulse.

Similarly, the sweep speed of each trace is adjustable in steps. Sweep speed is coded on the record by programming an extra sweep

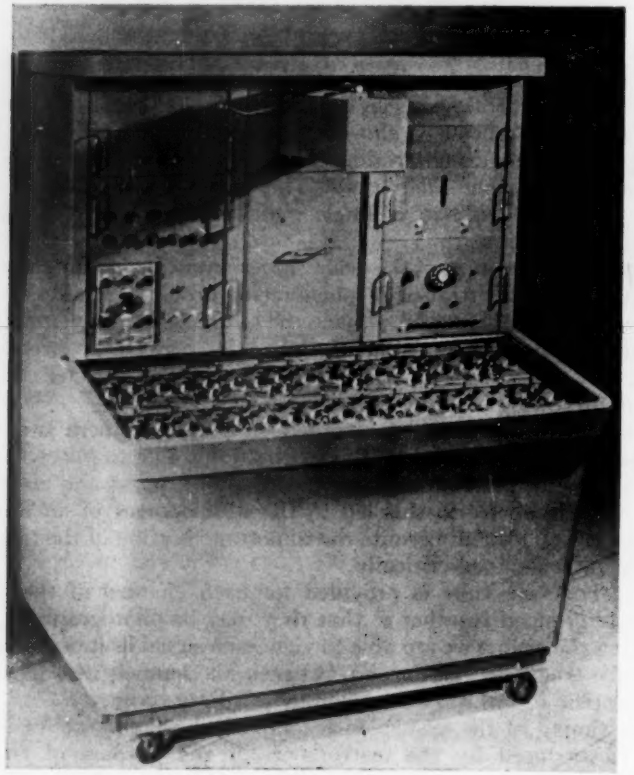

FIG. 1. Twelve-channel sequential event recorder.

and simultaneously modulating the beam intensity. The dashed trace thus produced indicates the prevailing sweep speed by virtue of the length, spacing, or number of dashes.

Each channel also has its own signal amplifier and step attenuator. Attenuator settings are coded in the same manner as delay, thus registering all conditions of the test on the photographic film with the associated record.

These features, performed electronically, provide an instrument

superior to the drum camera for recording certain transient phenomena. Through the recorder's use the records may be expanded in the critical regions and the recording conditions made optimum for the signal in each channel. The photographic record is examined in a projection reader which magnifies the original cathode-ray image about two times. Programming for calibration and recording is automatic.

It is expected that this type of instrument may be useful in recording mechanical strains and in studying chemical kinetics, where drum

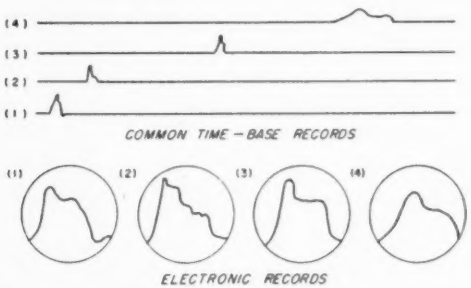


FIG. 2. Drum camera records and oscilloscope traces of typical transients.

cameras have been employed in the past. The instrument is also somewhat less expensive to construct, in that the precision mechanical parts of the drum camera have been eliminated. The first instrument described here was sponsored by the Army Ordnance Corps, Watertown Arsenal Laboratory. A more detailed account of certain novelties in the electronic system will be published at a later date.

## BOOK REVIEWS

SPHEROIDAL WAVE FUNCTIONS INCLUDING TABLES OF SEPARATION CONSTANTS AND COEFFICIENTS, by J. A. Stratton, P. M. Morse, L. J. Chu, J. D. C. Little and F. J. Corbato. 613 pages, 8½ × 11 in. New York, The Technology Press and John Wiley & Sons, Inc.; London, Chapman and Hall, Ltd.; 1956. Price, $12.50.

The most useful technique for obtaining solutions of problems in the partial differential equations of mathematical physics can be described as follows:

1. The partial differential equation is expressed in an orthogonal coordinate system appropriate to the boundary conditions of the problem. "Appropriate" usually means that one of the coordinate surfaces coincides with the boundary surface.

2. It is assumed that the variables are separable in the solution. This means that the solution can be expressed as the product of functions each of which involves only one of the variables.

3. If we are lucky, the partial differential equation will now be separable. That is, the partial differential equation can now be reduced to a set of ordinary differential equations, one for each of the coordinate variables.

4. The solutions of the ordinary differential equations yield the solution to the original problem, and if we are still lucky, the solution functions will already exist in tabulated form.

As an example, when the wave equation is expressed in cylindrical coordinates, this results in the second order ordinary differential equation known as Bessel's equation whose solutions are Bessel's functions, or cylinder functions. Since these functions are tabulated, there is a large class of problems that can be readily solved by this technique.

However, even though an orthogonal coordinate system is suitable, and steps 1, 2, and 3 can be carried out, luck might not hold through step 4 because the solution functions might not exist in tabulated form. The book under review helps to enlarge the field of physical problems that can now be readily solved by the technique we have described because it tabulates the solutions of the wave equation when expressed in spheroidal coordinates. The solutions of this partial differential equation in this coordinate system are known as spheroidal wave functions.

The book contains a brief discussion of spheroidal wave functions and an introduction to the tables. However, the bulk of the book (somewhat over 500 pages) is devoted to tables of the functions. The interesting feature of these tables is that they were computed and automatically typed on the Whirlwind I high-speed digital computer at M.I.T. The tables in the book are a photo-offset reproduction from the automatically typed ones, and should, therefore, be relatively error-free. The total computer time (exclusive of programming and transcribing) was about ten hours!

H. L. PLATZER

TRANSISTORS I, by RCA Laboratories Staff. 676 pages, illustrations, 6 × 9 in. Princeton, N. J., RCA Laboratories, 1956. Price: $4.50 (domestic); $4.70 (foreign).

A number of papers, some previously published and some unpublished, have been presented in book form by the Radio Corporation of America. The role of this volume would seem to be a kind of technical anthology related to transistors.

The chief similiarities which these papers hold in common are that they were all written by RCA authors and that they deal with transistors. Pondering further the significance of the book, one must observe that the general subject of transistors has already grown so broad that its specialized subtopics often have very little in common with each other. Hence, we have here a collection of interesting articles, but relatively little continuity of subject matter.

The diversification in this volume is very great, and one is inclined to wonder whether the person seeking information on the "Calculations of Alloying Depth of Indium in Germanium" is likely also to be interested

in the details of "A Pocket-Size Broadcast Receiver." Moreover, most of the papers in the book seem to be rather specialized in their treatment, and it is difficult to bridge the large gaps that exist between them.

Hence, as far as the reader is concerned, it could be wished that information on transistors might be provided according to a more systematic breakdown of the subject. The present state of the art already yields a large amount of theory dealing with the solid state physics of transistors and semiconductors. A second subtopic is the large body of experience in the fabrication and processing of transistors in manufacture. Electrical properties and circuit applications embody a third area. The latter could of course be further divided into communications, computers and industrial equipment applications. For the student there is also a continuing need for those introductory books with a broad and less detailed coverage of the whole subject. So far only a few books have been offered which fit into these several categories, but before long a goodly number will inevitably follow.

In summary it might be said that *Transistors I* will be a worthy addition and a convenience for anyone wishing to assemble a library on the general subject of transistors. On the other hand, it will not serve as a text or reference on the subject because of the specialization and diversity of the individual papers. It is incidentally a little puzzling that so many unpublished papers should have been available. It would seem better to make these papers available through the periodicals as soon as they are written, and to concentrate efforts on indexing the information for ready reference by those who need it. Perhaps Transistors II, if and when published, could be edited to fit this valuable information more logically into recognized categories. C. W. HARGENS

NUCLEAR MAGNETIC RESONANCE, by E. R. Andrew. 265 pages, diagrams, 5⅛ × 8⅛ in. New York, Cambridge University Press, 1956. Price, $6.50.

Since the discovery of nuclear magnetic resonance, some four hundred articles or more have appeared in various scientific publications. However, Andrew has given us the first comprehensive book devoted solely to the subject.

Certain nuclei possess intrinsic spin and angular momentum, and it can be shown that if such nuclei are placed in a magnetic field the angular momentum becomes quantized giving rise to nuclear Zeeman levels. It is the transitions between these energy levels which are observed in nuclear magnetic resonance experiments.

In Chapter 1, the author introduces the reader to the subject by briefly tracing the history of nuclear magnetic resonance. Short descriptions are given of the experiments of Lasarew and Schubnikow with solid hydrogen, the molecular beam technique of Rabi and his contemporaries and the discovery of nuclear resonance in solids by the groups led by Purcell and Bloch.

Chapters 2 and 3 adequately discuss the basic theory and experimental methods. The chapter on experimental methods is especially well presented. Andrew has given clear descriptions of the various techniques used in observing resonance signals. He has included many circuit diagrams and describes how the experiments must be designed in order to give the highest signal to noise ratio. The attainment of optimum signal to noise ratio is often a crucial requirement in these experiments since one must couple a system of relatively few participating nuclei to a delicately tuned electronic circuit.

Other chapters deal with the measurements of thermal and spin-spin relaxation times in gases, liquids, metallic and non-metallic solids. Space is also devoted to the determination of nuclear properties.

Determinations of high precision are now possible of the nuclear moments for a large number of elements. Through determinations of the ratio of the Bohr and nuclear magneton, it is now possible to obtain the value of such constants as the Faraday and the proton-electron mass ratio to an accuracy of thirty parts per million!

Chapter 8 deals with Quadrupole effects which are the result of the interaction of interval electric fields with the nucleus. In the study of solids, this quadrupole coupling is a powerful method of studying the gradient of the internal electric fields of crystals.

The eight chapters in this book give the reader much more than a casual introduction to the field. The material presented would be invaluable for anyone contemplating work

in nuclear resonance. The appendix and bibliography deserve special mention. The writer has included extensive tables of spectra, and listings of liquids and solids which have been investigated along with copious references.

This book which is one of the latest of the Cambridge Monograph series is highly recommended. J. B. DREW

ADVANCED ANALYTICAL CHEMISTRY, by Walter Wagner, Clarence J. Hull, and Gerald E. Markle. 282 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1956. Price, $6.00.

*Advanced Analytical Chemistry*, a text concerned only with the inorganic branch of analysis, was designed primarily for the beginning graduate student although it is of value to others such as analytical chemists and materials engineers. Its function is to serve as a bridge between undergraduate courses and the more recent developments in analytical chemistry.

Much credit can be attributed to the authors for they have succeeded in preparing a text in which the language is succinct, and which reduces a difficult subject to terms simple enough to make easy and interesting reading.

Aside from its literary merits, the book is technically competent. In part I can be found discussions on the theories behind the most popularly used instrumentation techniques and the latest analytical procedures. For those who desire to explore more deeply, ample references are given. Of particular merit is the chapter on the use of organic reagents since the authors have treated this topic with the growing recognition that this technique deserves. Also noteworthy is the acknowledgment that has been accorded to the use of statistics in chemistry.

The entire second part has been devoted exclusively to the analysis and separation of the elements, including the rarer elements which can be expected to become more and more important as the complexities of modern technology increase. Here too the authors have done well. They have managed to condense an immense field into a few compact chapters, effectively supplementing the text with many references.

The book does have a weakness and this arises from the authors' attempts to embrace so many facets of analytical chemistry. They have tended to over-simplify the techniques involved in the analytical procedures. Again, congratulations are in order to Messrs. Wagner, Hull and Markle for providing such an effective guide for the analytical chemist.

MARVIN PACKER

INTRODUCTION TO NUMERICAL ANALYSIS, by F. B. Hildebrand. 511 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $8.50.

There has been a need for additional books in Numerical Analysis for some time. The increasing use of high-speed digital computing machines has given rise to a small amount of research in this field, but has led to an even greater demand for material already in published form.

Professor Hildebrand's book is designed as an introductory text, and results from a set of notes prepared for classroom use at the Massachusetts Institute of Technology. The author had calculating equipment in mind, and his book deserves to be on the shelf of the numerical analyst.

Included are the standard topics of interpolation, numerical differentiation and integration, and the approximate solution of equations. A wise selection is made in starting with a discussion of errors and significant figures. A sufficient amount of finite differences is included to prepare the user for the numerical methods to follow. These include the methods of Runge-Kutta, least squares, Hermite and Chebyshev polynomials, and quadratures. For solution of algebraic equations the methods of Gauss, Crout, Gauss-Seidel and Graeffe are presented as well as various iterative methods such as Lin's and Bairstow's.

The text is supplied with a large number of exercises at the end of each of its ten chapters, a bibliography of two hundred seventy-six references and a rather unique appendix entitled "Directory of Methods." In the last, the various methods are enumerated (with references to specific paragraphs in the text) under the general headings: Interpolation, Approximation, Numerical Differentiation, Numerical Integration, Summation of Series, Smoothing of Data, Numerical Solution of Ordinary Differential Equations,

Numerical Solution of Equations, and Miscellaneous Processes. A short index concludes the book.

The serious user of numerical analysis will have to go beyond this book for such things as the Monte Carlo Method. For this reason he should supplement this text with another such as Householder's, "Principles of Numerical Analysis." Together these McGraw-Hill books are sure to be in great demand both in the classroom and the computer laboratory. DONALD B. HOUGHTON

AIRCRAFT IN DISTRESS, by Harley D. Kysor. 432 pages, illustrations, 5½ × 8¼ in. Philadelphia, Chilton Company, 1956. Price, $6.00.

In *Aircraft in Distress*, author Kysor has assembled in one volume, for the first time, all available information pertinent to insuring—if not always an entirely happy ending—at least a less disastrous ending to aircraft mishaps than would otherwise result.

Experience has proved that the margin between an incident and a catastrophe is often very narrow, and that in many cases the determining factor will be the earliness of recognition of the situation, and the promptness and correctness of the action taken by those involved. With this in mind, the author has endeavored to describe and evaluate all the aids available for aircraft safety, their uses and limitations; to enumerate all the adverse conditions and problems which may confront one who goes in the air; and to set forth reasonable courses of action either to prevent their occurrence or to minimize their effect, whether they be due to pilot errors, mechanical failures, weather, or what not.

Topics discussed vary from prevention and cure of carburetor icing, and the proper direction (with respect to wind, waves and swells) in which to ditch a disabled aircraft at sea, to the best method of getting out through a small window.

While written primarily for those whose business is connected with flying—pilots, flight crews and ground crews—the book will prove of interest and value to anyone who goes into the air. A knowledge and understanding of its contents could well contribute to a further reduction of the already low accident rate incident to aviation.

R. S. BARNABY

ANNUAL REVIEW OF NUCLEAR SCIENCE, VOL. 5 (1955), edited by James G. Beckerley. 448 pages, 6 × 8¾ in. Stanford, Annual Reviews, Inc., 1955. Price: $7.00 (domestic); $7.50 (foreign).

In this fifth volume of this useful series, the Editorial Committee has reviewed its opinions on scope, space allocation, reader interest and timing of articles. While they inveigh against the too brief, annotated reference list type of article, they do include one such article on vertebrate radiobiology. The Editorial Committee is concerned with whether radiation chemistry should be considered in nuclear science or in physical chemistry. Yet they include an article "Industrial Applications (Mass Spectrometry)" which seems far removed from nuclear science. It should be evident that too much dilution of effort by too great a scope should lessen the value of the series. .This reviewer still feels that the inclusion of radiobiology is an error.

On the whole the review articles are well written, well organized and well documented. Such annual reviews are generally welcome to those scientists who are interested but much too busy to read the original literature. Some of the reviews go back to the early days of nuclear science and give a complete review. Others are concerned with the last year or two, since the appearance of an earlier review. There are subject and author indices and chapter title and chapter author indices for Volumes 1 through 5 of the series, in the present volume.

The contents include three theoretical nuclear physics chapters—"Electromagnetic Transitions in Nuclei," "The Distribution of Charge in the Nucleus," and "Nuclear Reactions of Intermediate Energy of Heavy Particles"; four experimental or applied chapters—"Nuclear Radiation Shielding," "Nuclear Particle Detection," "Design Comparison of Reactors for Research," and "Fundamentals of Radioautography"; three chapters on radiation chemistry—"Radiation Chemistry," "Mass Spectra and the Chemical Species Produced by the Impact of Low Energy Electrons" and "Radiochemical Separation Techniques"; and three radiobiology chapters—"Cellular Radiobiology," "Removal of Radioelements from the Mammalian Body," and "Vertebrate Radiobiology: Physiology." LEONARD MULDAWER

TEMPERATURE: ITS MEASUREMENT AND CONTROL IN SCIENCE AND INDUSTRY, edited by Hugh C. Wolfe. 467 pages, illustrations, charts, 6 × 9 in. New York, Reinhold Publishing Corp., 1955. Price, $12.00.

In October 1954 the American Institute of Physics, the National Bureau of Standards and the Office of Ordnance Research of the Department of the Army were the official hosts of the Third International Symposium on Temperature, held in Washington, D. C. The proceedings of this group of meetings, numbering twenty-four papers, constitutes the book under review. It becomes a companion volume, with little duplication, to its predecessor of over a decade ago, with somewhat more emphasis on the basic concepts of temperature and means for its measurement. In spite of the fact that a multiplicity of authors from the United States and abroad wrote individual chapters, the editor has welded together the separate contributions into a whole which is clearly readable and with little jumpiness of style which is so often seen in such volumes.

The papers are grouped into five sections: general concepts of temperature; standards and scales; transient phenomena; experimental measurements; and miscellaneous topics.

The concept of what constitutes a description of temperature is not unique. Near absolute zero, where disordered electronic motion exists to but a small degree, the concept is different from that useful in the range of temperatures where the state of a disordered system can be described in terms of its statistics. Again, for high gas temperatures, such as may be encountered practically in certain phases of the development and use of high speed missiles, the optical concept is useful. And in the field of astrophysics, still another temperature, related to spectroscopic descriptions of the phenomena investigated is of greater interest. These four are treated in the first part of the book.

In somewhat greater detail, fifteen chapters discuss the 1954 revision of the international temperature scale, the reasons for choosing and the means for measuring the fixed points on the various temperature scales, and measurement techniques. The fixed points range from less than 2.5 K through the triple point of water, to a molten metal like gold or zinc. Measuring temperatures over a wide range requires special devices suitable for the concept which best describes temperature in smaller range intervals. Thus gas thermometers, precision resistance thermometers, optical pyrometers, semiconductors, superconductors, and the measurement of the velocity of sound are all useful devices or basic techniques.

The highest man-made temperatures have existed in the cores of atomic or nuclear explosions. An interesting chapter discusses the rise and fall of the temperatures and energies associated with such reactions. These are phenomenally large—50,000,000 K—perhaps even too large to suit any present concept of temperature. A chapter on temperatures in the upper atmosphere closes the book.

Any scientific or professional worker who is at all concerned with the problems and understanding of temperature measurement and control will find this book an indispensable source and reference work. Supplementary to the text are the lengthy lists of references to other papers which close each of the chapters. It is probably the most complete book on the subject published in the past decade. S. CHARP

## PUBLICATIONS RECEIVED

RESISTANCE OF MATERIALS, by Fred B. Seely and James O. Smith. Fourth edition, 459 pages, diagrams, 5½×8½ in. New York, John Wiley & Sons, Inc., 1956. Price, $6.50.

FUNDAMENTAL MATHEMATICS, by Thomas L. Wade and Howard E. Taylor. 380 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $4.75.

THE AIM AND THE END, by Sir James Colquhoun Irvine. 313 pages, 5½ × 8½ in. Fair Lawn (N. J.), Essential Books Inc., 1956. Price, $3.40.

UNITED STATES ARMY IN WORLD WAR II. THE WAR DEPARTMENT. GLOBAL LOGISTICS AND STRATEGY 1940–1943, by Richard M. Leighton and Robert W. Coakley. 780 pages, maps, illustrations 6¾ × 9¼ in. Washington, Government Printing Office, 1956. Price, $6.25.

## BOOK NOTES

LEGAL PROBLEMS IN ENGINEERING, by Melvin Nord. 391 pages, 5¾ × 9 in. New York, John Wiley & Sons, Inc., 1956. Price, $7.50.

The author is both an engineer and a practicing lawyer; thus his advice to engineers about legal matters is authoritative. The book is designed as a text, but it serves equally well as a handbook for practicing engineers. After an introduction to basic law, a large portion of the book (over 200 pages) is devoted to Legal Principles for Engineers, covering contracts, sales, insurance, personal and real property, workmen's compensation, public utilities, municipal corporations and labor laws. A short section of ten pages treats ethical responsibilities and professional registration of engineers. A final section of about a hundred pages discusses Engineering-Legal Problems, with subsections covering construction contracts and specifications, governmental regulation of business, patents, copyrights and trademarks, and air and stream pollution. Actual "cases" are presented in condensed form, to illustrate points under discussion. As a help in avoiding legal difficulties, this book is recommended to engineers in all fields.

ENGINEERING IN HISTORY, by Richard Shelton Kirby, Sidney Withington, Arthur Burr Darling and Frederick Gridley Kilgour. 530 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $8.50.

With two engineers and two historians collaborating in this history, the end product is an interesting general discussion of the effect of engineering on Western history, and vice versa. Beginning in 6000 B.C. (when man first began to produce his food), through the appearance of urban society (3000–2000 B.C.), the book then treats Greek science, the power revolution in the Middle Ages, the rise of modern science in the 17th century, the Steam and Industrial Revolution in the 18th century, electricity and applied science in the 19th century, and finally automatic control for the present century. The text is liberally interspersed with fine photographs, reproductions of bas relief, pen and ink sketches and maps. To those wont to believe that all engineering blessings are modern, this book is recommended for upsetting their beliefs; to all others, it is recommended as very interesting reading.

THE THEORY OF FUNCTIONS OF REAL VARIABLES, by Lawrence M. Graves. Second edition, 375 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $7.50.

The second edition of this book, first published in 1946, incorporates two new chapters. One deals with the general theory of sets, relations and functions, the axiom of choice, and the several commonly used propositions which are equivalent to it. The other new chapter introduces the general theory of metric spaces. Minor changes have been made elsewhere in the text; for example, several proofs have been simplified and some errors have been corrected. Outside of these few changes, the material from the first edition is essentially unaltered. This new edition—with its two new chapters—was prepared to help the student in the modern tendency toward the abstract point of view.

ESSENTIALS OF QUANTITATIVE ANALYSIS, by A. A. Benedetti-Pichler. 666 pages, diagrams, 6 × 9 in. New York, The Ronald Press Company, 1956. Price, $15.00.

A new text in the field of chemical analysis, this volume stresses the techniques and unit operations common to many specialized areas of chemical analysis. The instructions are detailed, so that reproducible results are assured. The material is divided into an introductory section, and four main sections—Measuring and Measuring Instruments, Preliminary Tasks, Analytical Operations and A Course of Study. The Appendices contain a valuable short section on how to locate literature references, one on the administra-

tion of a laboratory, and 40 pages of useful tables. A practical feature is a complete listing of the experiments covered, with appropriate indications for those suitable in an introductory course. The author's main objective in writing the book is to develop facility in the use and critical evaluation of the literature.

FLUIDIZATION, edited by Donald F. Othmer. 231 pages, diagrams, 6 × 9 in. New York, Reinhold Publishing Corp., 1956. Price, $7.00.

As the first book on fluidization and its applications to chemical engineering, this will be welcomed by chemical engineers, metallurgists, petroleum processors, physical chemists and management personnel in those industries using the process. Although the book is based on a 1955 symposium sponsored jointly by the Polytechnic Institute of Brooklyn and the A.I.C.E., it has been enlarged to include additional material. The contributors include two P.I.B. teachers, three engineers, two vice presidents of companies, three managers of company engineering departments, an associate director of research, and a manager of sales. With such a varied list of authors, the subject of fluidization is treated from a variety of viewpoints. The nine papers cover fluid dynamics, heat and mass transfer, graphical analysis, history, operation, fluid coking, design and control techniques, catalytic cracking and applications.

THE WORLD OF ATOMS, by J. J. G. McCue. 659 pages, illustrations, 6 × 9 in. New York, The Ronald Press, 1956. Price, $6.50.

*The World of Atoms* is essentially a textbook designed for freshmen and sophomores who do not plan to continue in science. It is skillfully written and the ingenious arrangement of subject material makes it applicable to any of the introductory courses in the physical sciences.

By subtly choosing the title, the author is able to treat almost every facet of science taught. Atoms figure in motion and so the opening chapter is on mechanics. The laws of motion are set up for the solar system so that later they may be used in nuclear reactions. Likewise, heat and chemistry deal with motions—not of atoms as single entities but as clusters of atoms we call molecules. The combinations of these in solution with a background section on electricity permits a thorough understanding of electrolysis.

The remainder of the book deals with the elements, the structure of atoms, chemical binding and the atomic nucleus.

*The World of Atoms* is a well conceived introduction to the physical sciences and may prove a popular text for survey courses.

THE MICROBE'S CONTRIBUTION TO BIOLOGY, by A. J. Kluyver and C. B. van Niel. 182 pages, diagrams, 5¼ × 8¼ in. Cambridge, Harvard University Press, 1956. Price, $4.00.

This book is the printed version of the "John M. Prather Lectures" delivered by the authors at Harvard in 1954. The authors contend that to understand the living world it is necessary to unveil the role which microorganisms play; otherwise the picture is seriously distorted. The entire picture must include the simple cells as well as the much studied and discussed higher forms of life. They believe that microbiological research will indicate the crucial role which microbes may play in establishing fundamental biological concepts.

EXPERIMENTS IN THE PRINCIPLES OF SPACE TRAVEL, by Franklyn M. Branley. 119 pages, diagrams, 5¼ × 8 in. New York, Thomas Y. Crowell Co., 1955. Price, $2.00.

The principles of space travel are not too well understood by the lay public. Confusion exists between scientific fact and fiction. To make clear the essential differences between the two the author has cleverly designed some experiments which illustrate the scientific principles involved in leaving the earth.

In *Experiments in the Principles of Space Travel*, Franklyn Branley has taken subjects like temperature, pressure, gravity, power and distance and has treated them by analogy. This type of education complemented by ingenious experiments is the easiest to assimilate. It provides a basic frame of reference for those interested in the subject.

## CURRENT TOPICS

**Breakthrough Made in Releasing Sun's Energy.**—Air Research and Development Command scientists have achieved the first step in unlocking the vast storehouse of energy in the high upper atmosphere. An Aerobee rocket equipped to release nitric oxide gas under high pressure was sent to an altitude of 60 miles above the desert sands of Holloman Air Development Center, New Mexico, on March 14 and accomplished a breakthrough that has been the subject of speculation by geophysicists for the past ten years—releasing the energy chemically stored by the sun in the upper atmosphere.

When the nitric oxide gas was automatically released, observers saw what first appeared to be the formation of a new star, nearly twice the brightness of the planet Venus. The light was reported by observers more than 60 miles away from the ARDC launching site. In less than ten minutes the "star" had grown in size so as to appear to an observer on the ground to be about four times the diameter of the moon.

By increasing the natural amount of nitric oxide in the atmosphere by a factor of several billion, the rocket released gas was able to unlock the chemically stored sunlight in vast quantities. This action produced the spot of light in the upper atmosphere which spread to approximately three miles in width before the nitric oxide gas thinned out and reduced the brightness of the light.

Although the spreading of the light was visible to the naked eye for approximately ten minutes, sensitive instruments at observing stations on the vast Holloman range were able to detect the light for a much longer period.

ARDC geophysicists have termed the experiment "a major breakthrough."

Working under the direction of Dr. Murray Zelikoff of the Air Force Cambridge Research Center, the scientists discovered in the laboratory that energy locked in atomic oxygen could be released by the addition of a gas containing one atom of nitrogen and one atom of oxygen. Chemically, this combination is known as nitric oxide (NO).

Nitric oxide has the property of bringing two oxygen atoms together to form an oxygen molecule and release light. The gas is not used up in the process, but is used over and over again without being exhausted. The process occurs naturally in nature, but the natural abundance of nitric oxide gas is so small that its natural glow in the sky must be detected at night by instruments many times more sensitive than the naked eye.

Scientists have known for many years that if they could find some way for the separate oxygen atoms to combine together rapidly, a light many times stronger than natural light in the atmosphere could be emitted.

The light thus produced is actually sunlight which has been stored chemically in the oxygen atoms and can now be released.

The experiments may eventually lead to means of extracting this energy for such uses as the propulsion of rocket ships high in the earth's atmosphere.

Another "first" scored by the

ARDC scientists came on March 12, when a preliminary Aerobee flight was launched releasing nitric oxide gas during daylight. This test was to observe the ability of sunlight to react on the nitric oxide gas during the daytime. It was found that the action of the sunlight on the gas produced an artificial cloud of charged particles which reflected radio waves in the same manner as the ionosphere.

The ionosphere is the layer of the earth's atmosphere that ranges from an altitude of about 50 miles to 250 miles. It has been found that radio waves "bounce" from the ionosphere and allow long range communication.

During the experiment, scientists "bounced" radio signals from the charged cloud in the same way that light is reflected from a mirror. They feel that man made ionospheric clouds produced in a series may pave the way for increasingly effective long range communications.

**Radio Telemetering Speeds Missile Design.**—Key to successful design of intercontinental rockets, space satellites and fighters, both manned and unmanned, to protect our cities, is exact knowledge of how high-speed aircraft perform in flight. Only with this information, can engineers work out effective control and guidance systems. Radio telemetering, a means for retrieving flight-test data, drew attention from engineers attending the 44th annual convention of the IRE.

Test pilots cannot ride rockets, nor can they watch hundreds of strain gages and other measuring devices while flying conventional aircraft. The answer is to radio the information to the ground where it can be studied at leisure. One system to be described checks 24,000 measurements every second. Accuracy is one part in 256.

When piloted aircraft are tested, additional information can be gathered by rugged portable magnetic tape recorders especially designed for acquiring engineering information during flight. More elaborate magnetic tape recorders are installed at ground stations to take down the information radioed from airborne telemetering transmitters.

Final step in checking out experimental airframes is to compile the telemetered information in form that aeronautical engineers can use in revising their designs. Much of this data reduction can be done on giant electronic brains such as the IBM 700 machines. However, a special-purpose computer called a data transcriber must be installed ahead of the general-purpose computer input to convert from telemetering language to computer language.

One such computer is called IDIOT. The name stand for *I*nstrument Lab *DI*gital *O*n-line *T*ranscriber. The machine, however, does not deserve its bad name. Far from it: IDIOT can transcribe more than three million items of information during an eight-minute test run.

**Device Measures 400,000 F.**—For the first time under laboratory conditions, man has produced temperatures of well over 400,000 F. and corresponding brightness 700 times greater than at the surface of the sun. The incredible temperature and subsequent brightness were a result of investigations into the physics of high energy, high temperature gaseous discharge by scientists of the Air Research and Development Command.

This important work has been accomplished in connection with a classified project of ARDC's Air Force Cambridge Research Center.

However, the technique itself is not classified, and holds promise of possible use for industrial and research organizations.

Temperatures which have been measured by the laboratory are of exceedingly short duration, less than a millionth of a second, but an important outgrowth of this research was the design of equipment capable of accurately measuring the powerful and extremely fast pulsed electrical spark discharge.

The extremely high temperatures involve the release of electric energy into a very small volume of inert gas under high pressure.

A specially designed capacitor circuit is employed to store the energy and release the electric discharge. This capacitor circuit, applied to the basic gaseous discharge technique, is primarily responsible for the resultant high temperatures.

In the past, those working in the field were unable to determine with accuracy the temperatures which they were able to generate. Now, because of ARDC's newly devised equipment, an accurate measurement of the temperature and the brightness is calculated.

**Tiny ac-dc. Converters for Trains.**—A new device for converting alternating current to direct current, which was on display at this year's British Industries Fair in London on April 23, is made up of a series of 1-k.w. units each about the size of a half-dollar.

Powerful enough for locomotive use (installation has already been made successfully on a passenger train in Britain), the new germanium rectifier can be conveniently housed in trays built under the floor of the engine. This compares with the conventional type of mercury arc rectifier, which is normally sited in special brick substations alongside the railroad track.

The device is air-cooled and has a 750 k.w. capacity, arranged for full-wave rectification. It is expected that it will be used in the British Railways' massive electrification program.

Important features of the rectifier include its high conversion efficiency, the small amount of space it occupies, and economy of maintenance costs. All units are hermetically sealed and proof against humidity.

The development of British Thomson-Houston Co. engineers, other forms of the rectifier are being perfected for various purposes—to increase the light output from movie projectors (for the new large screens), for hydrogen production in an electric light globe works, and so forth.

Ultimately it is visualized that germanium rectifiers will be employed by a variety of industries, such as electro-plating, copper-refining and hydrogen production where exceptionally heavy currents of low voltages are required.

**Induction Motor for Business Machines.**—A new four-pole business-machine motor less than three inches in diameter and weighing under four pounds, has been developed by the General Electric Company's Specialty Component Motor Department.

Designed to meet new adding machine and typewriter specifications, this induction motor is forty per cent smaller than other GE motors of similar rating.

Weighing $3\frac{3}{4}$ lb., this M49-frame motor is 5 in. long and 2.97 in. in diameter. Of permanent split capacitor design, it has an improved resilient single bonded ring mounting for quieter operation.

Based on 2000 hr. of operation a

year, only one cubic centimeter of oil has to be added to each bearing every two years, according to company engineers.

**Electronics to Aid Earth Satellite.**—Electronic devices may make it possible for newspapers to tell their readers daily where and when to look for the earth satellite. This was the prediction of one of a panel of seven scientists who discussed the earth satellite program at the recent Institute of Radio Engineers convention.

The radio system known as "Minitrack" will supplement weather-dependent optical methods for keeping track of the progress of the satellite about the earth and will provide through electronic computers, immediate information on its position.

In describing this radio tracking system, John T. Mengel, Naval Research Laboratory, revealed that details of a simplified version of Minitrack will be made available at a later date to radio amateurs so that they may join amateur astronomers in observing the satellite.

In outlining the tracking problem which Minitrack must solve, Mr. Mengel compared it with the problem of finding and following a golf ball thrown out of a jet airplane traveling at 60,000 feet with the speed of sound.

In addition to locating and tracking the satellite, Minitrack will be used to obtain scientific data telemetered or radioed back to earth. Telemetering will also be used to measure the performance of the 3-stage rocket system which will place the satellite in its orbit.

**Cold Extrusion of Titanium.**—Cold extrusion of titanium has been successfully accomplished for the Air Force. Although only pure titanium has been extruded by the new process, it is hoped this will pave the way for similar work with the more widely-used titanium alloys, and perhaps permit use of titanium for a new series of small airplane parts.

The Air Research and Development Command stated that the cold extrusion process could ultimately permit the manufacture of small titanium parts that would need little machining. The process is done at room temperature where the highly-active titanium is not contaminated by gases in the atmosphere.

The research project was conducted for ARDC's Wright Air Development Center by Battelle Memorial Institute, Columbus, Ohio.

In operation, a solid rod of pure titanium (called a billet), about 1.5 in. in diameter and 3 in. long, is coated in a phosphate-fluoride chemical bath, developed by Battelle. The billet is inserted into an extrusion chamber, in the air and at room temperature. A punch then forces the billet through a die under pressures of about 100,000 to 280,000 pounds per square inch. As the titanium passes through the die, it assumes the desired shape—in this case a rod of reduced diameter.

During the process, a petroleum base moly-disulfide-graphite lubricant is used to prevent the titanium from seizing to the extrusion tools under the extremely high pressure. The phosphate-fluoride coating tends to hold the lubricant to the titanium, thus making the operation easier.

The present physical limits on tools and the pressures involved in the process would restrict cold extrusion to the production of small items only. Large titanium parts can be successfully extruded in the "hot" process.

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